Mines and Minerals Division

Ontario Geological Survey
Open File Report 5690

Ontario Geoscience Research Grant Program

Grant No. 266

Anomalous Carbonate Till Near Hemlo and Geraldton: Origin and Applications

1988

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MINES AND MINERALS DIVISION

ONTARIO GEOLOGICAL SURVEY

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Anomalous Carbonate Till Near Hemlo and Geraldton: Origin and Applications

by

S.R. Hicock

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V.G. Milne

V.G. Milne, Director
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ONTARIO GEOSCIENCE RESEARCH GRANT FUND

Final Research Report

Foreword

This publication is a final report of a research project that was funded under the Ontario Geoscience Research Grant Program. A requirement of the Program is that recipients are to submit final reports within six months after termination of funding.

A final report is designed as a comprehensive summary stating the findings obtained during the tenure of the grant, together with supporting data. It may consist, in part, of reprints or preprints of publications and copies of addresses given at scientific meetings.

It is not the intent of the Ontario Geological Survey to formally publish the final reports for wide distribution, but rather to encourage the recipients of grants to seek publication in appropriate scientific journals whenever possible. The Survey, however, also has an obligation to ensure that the results of the research are made available to the public at an early date. Although final reports are the property of the applicants and the sponsoring agencies, they may also be placed on open file. This report is intended to meet this obligation.

No attempt has been made to edit the report, the content of which is entirely the responsibility of the author(s).

V.G. Milne
Director
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ANOMALOUS CARBONATE TILL NEAR HEMLO AND GERALDTON:
ORIGIN AND APPLICATIONS

Ontario Geoscience Research Grant Program
Grant No. 266

by

Stephen R. Hicock[1]

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[1] Department of Geology, University of Western Ontario

Manuscript approved for publication by V.G. Milne, Director, Ontario Geological Survey, July 8, 1988.

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Objectives

The project was initiated to determine the significance of anomalous calcareous tills in the Hemlo and Geraldton areas to gold exploration. To do this I had to find out how many tills occur, how the tills formed, where they came from, and how their presence affects drift prospecting strategy. Their effect on acid rain buffering was also of interest. It was hoped that a depositional model could be developed to explain the occurrence of the distal till resting on Precambrian Shield terrain, as well as to gain some insight into the behaviour of the Laurentide Ice Sheet between Lake Superior and James Bay.

Methods

Field work was done during July of 1985 and 1986. Seven and eleven sites were studied in the Hemlo and Geraldton areas, respectively. Sites were cleaned, documented, and sampled. Samples were then analyzed in the laboratory for grain size, carbonate, provenance, and geochemistry. Details are given in the reprints and preprints of the appendices.

Results

This study has revealed a region in which some lodgement tills are wrong for drift prospecting, whereas supraglacial tills are amoung the best. This is completely the opposite situation to most areas of glaciated terrain where lodgement till is normally the desireable sampling medium and supraglacial till of little interest.

It was found that much of the material in the calcareous tills had been glacially transported for more than 100 km from the James Bay Lowland and eastern Hudson Bay area. This means that most of the calcareous till material near Hemlo and Geraldton had been dispersed by glacier ice too far from any potential ore sources to be useful for tracing anomalies back to those sources. For the calcareous tills, Hemlo and Geraldton are well downglacier in the diffuse end of the tails of any dispersal trains. Even dispersal fans from closer Shield sources of ore would have been diluted and masked by the over-abundance of calcareous debris already held in the ice, rendering them unrecognizable as ore dispersal trains. Thus the carbonate tills are a hindrance to gold exploration in the study areas and should be avoided for drift prospecting. However, they are commonly as calcareous as southern Ontario tills and make excellent buffers for acid rain, as well as cores for acidic tailings dams.

The noncalcareous tills are more locally derived than the calcareous tills and are better candidates for drift prospecting. They tend to contain the highest metal content, which decreases in tills with increasing carbonate content (appendices 1 and 3). The supraglacial tills contain large angular blocks of Shield rocks most likely derived from uplands upglacier of Hemlo and Geraldton. This suggests a glacial transport distance of about 20 km, which implies that drift prospecting in the supraglacial tills may yield new ore sources a few tens of km away.

A depositional model was developed involving these uplands in combination with zones of rapid glacier flow within the Laurentide ice sheet (appendices 2 and 4). The uplands induced compressive flow on their stoss sides so that englacial ice overrode impeded basal ice, carrying abundant calcareous debris up over the uplands. The calcareous debris was derived from soft Paleozoic beds under James Bay and surrounding lowlands. While passing over the uplands the carbonate-rich englacial ice experienced extending flow and downward transport. On flowing into the lee sides of the obstructions, the englacial ice deposited distally-derived, calcareous, lodgment till. After the glacial maximum general ice melting occurred and the calcareous meltout till was formed on the calcareous lodgment till, however a reactivation of glacier movement carved drumlins in the Geraldton while depositing an upper calcareous lodgment till near Hemlo. Upshearing of debris from the stoss sides of the uplands high into the ice produced the supraglacial till which was deposited during final ice disintegration.

The occurrence of thick belts of distal carbonate till near Hemlo and Geraldton, surrounded by areas of thin calcareous or noncalcareous till, together with the remarkable lithologic similarity of the respective calcareous tills in both areas (see appendices), imply rapid ice flow within the Laurentide Ice Sheet with little modification of debris along the glacial pathway (appendices 3 and 4). This suggests ice streaming at least in the Hemlo and Geraldton areas. The calcareous tills are also muddy and would have been relatively impermeable substrata under a wet based glacier. They probably acted as soft deformable beds which enhanced (perhaps induced) ice streaming in a positive feedback situation. Thus, any ore particle concentrations within the ice stream would have been diluted by the rapidly transported calcareous debris, thereby masking the signatures of any dispersal trains.

Suggestions for Future Study

1) Systematic geochemical sampling of supraglacial and basal noncarbonate tills in both areas to detect any ore dispersal trains.

2) Detailed mapping of areas of thick calcareous till on the Canadian Shield to avoid for drift prospecting and to infer the pattern of ice streaming within the Laurentide Ice Sheet.

3) Similar study to this one in the Timmins area (and elsewhere) to see if the same situation occurs with carbonate tills, uplands, and ice streaming.

Appendices

Appendix 1:

Carbonate till on the Canadian Shield: economic and environmental implications in the Hemlo area, Ontario. reprint by S.R. Hicock

Reprinted from:

Geoscience Research Grant Program

Summary of Research 1985-1986

Ontario Geological Survey

Miscellaneous Paper 130, pp. 210-217. (1986)

Geology Department, University of Western Ontario

Contribution No. 726

Grant 266 Carbonate Till on the Canadian Shield: Economic and Environmental Implications in the Hemlo Area, Ontario.

Stephen R. Hicock

Department of Geology, University of Western Ontario London

ABSTRACT

Calcareous tills from the Canadian Shield are examined in order to determine how they were glacially transported and deposited, and how their occurrence near Hemlo could affect gold exploration, aggregate quality, and acid rain susceptibility.

Three calcareous tills deposited by lodgment and subglacial meltout are underlain by a basal noncalcareous till and overlain by a noncalcareous supraglacial meltout till. The entire till sequence can be explained by deposition during a single glacial advance over uplands. The model involves simultaneous stoss side upshearing to eventually produce supraglacial till, and lee side downshearing of englacial debris to produce subglacial tills, followed by stagnation.

Supraglacial till comprises coarse local Precambrian materials and is richest in metals. Carbonate tills are finer textured, are dominated by Paleozoic materials, and contain less metals. The supraglacial and the basal noncarbonate tills are the most likely to contain well defined ore dispersal trains that may be traced upglacier to source (probably within 20 km). The carbonate tills are too far-travelled to contain distinct and traceable trains; however, they should make excellent buffers against acid precipitation, as well as dam cores for acidic mine tailings ponds. Little chert occurs in the tills so that aggregate quality should be generally high.

INTRODUCTION

Many authors have documented the advantages of applying drift prospecting techniques to mineral exploration projects in glaciated shield areas of the northern hemisphere (*see* Shilts 1984 and his references) They recommended studying lodgment till (as opposed to other genetic types) because it is dominated by local clasts and should reflect nearby sources of till materials (Goldthwait 1971; Shilts 1975, 1984).

The carbonate till of this study occurs in an area where gold exploration has recently been extremely active. Thus, the genesis of the till has important implications for the usefulness of drift prospecting in the Hemlo area in finding other gold sources.

This study was initiated in order to assess the influence of the carbonate till on: 1) mineral exploration using drift prospecting, 2) the buffering of acid precipitation; 3) aggregate quality (cherts); and finally, 4) the determinion of till genesis and propose a depositional model for the area. These objectives will be accomplished by analyzing the till character and stratigraphy in order to interpret its mode of formation, occurrence, and provenance.

Field work during three weeks in July, 1985, concentrated on seven key exposures which were studied in detail for stratigraphic and structural relations of sediment units (Figure 266.1). In the laboratory, granulometric analyses were performed by the hydrometer-sieve method of the American Society for Testing and Materials (1972), using 0.002 mm and 0.063 mm as the clay-silt and silt-sand boundaries, respectively. Carbonate analyses were done on the -0.063 mm fraction after the method of Dreimanis (1962) and geochemical analyses were completed by Barringer Magenta Limited of Toronto, using atomic absorption techniques on total digests of the minus 0.002 mm fraction of till matrices.

Till criteria and terminology used in this paper follow the system of the International Quaternary Association's Commission on Lithology and Genesis of Glacial Deposits as summarized by Dreimanis (1982).

PHYSICAL SETTING AND PREVIOUS WORK

In the Hemlo area, uplands dominate the northern part, and low-lying areas containing abundant lakes dominate the southern, with a combined relief up to 220 m (Figure 266.1). The area is underlain by a structurally complex sequence of Precambrian lithologies including metavolcanic, metasedimentary, and granitoid plutonic and gneissic rocks (Muir 1982a, 1982b; Siragusa 1984a, 1984b, 1985a, 1985b). Diabase dikes have intruded other lithologies and rare patches of iron formation and ultramafic rocks (mainly peridotite) occur on the bedrock surface.

Recent Quaternary studies north of Lake Superior have concentrated on surficial mapping and glacial lake studies (Farrand 1962; Zoltai 1965a, 1965b, 1967; Boissonneau 1966); Zoltai and Boissonneau recognized the carbonate-rich till. Coker and Shilts (1979) generally described the till in a lake geochemistry study, and Fortescue and Geddes (1983), Geddes (1984a, 1984b, 1984c, 1985a, 1985b), Geddes and Bajc (1985a, 1985b), Geddes *et al.* (1985), and Woods (1985) have described it with more detailed mapping and case studies. Gartner and McQuay (1979, 1980) provided engineering and terrain studies of the area, and Cowan (1976) an aggregate inventory

TILL STRATIGRAPHY AND GENESIS

Five tills are recognized in the Hemlo area: three are calcareous and are sandwiched by noncalcareous tills. The oldest is a locally derived basal till observed in mine excavations by Geddes (1984a, 1984b, 1984c) and Geddes *et al.* (1985); it was not encountered in the sections studied by the author.

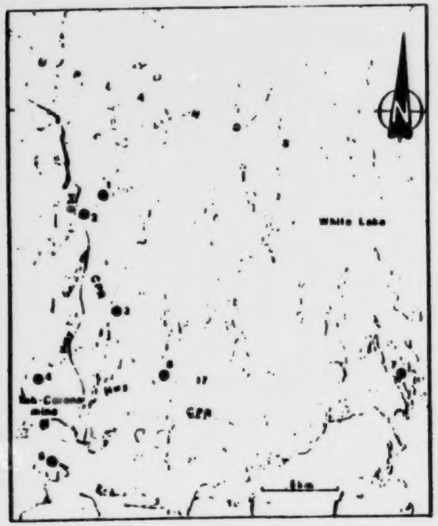

Figure 266.1. Topographic map of the study area with site localities. Contour interval is 76 m.

LOWER LODGMENT TILL

The overlying unit occurs in three sections and comprises dark grey, compact, calcareous diamicton. It is fissile, stony, and contains striated, faceted, and bullet-nosed stones, as well as clasts of sand at sites 2 and 7. Till matrix (-2.00 mm) comprises about 35% sand, 55% silt, 10% clay, and 35% to 40% total carbonates (calcite and dolomite; Table 266.1).

Stones are generally subrounded to subangular and dominated by Paleozoic lithologies, indicating distal glacial transport. Parallel and transverse alignment of stones in the till, extension fractures, and till wedges within the unit are consistently oriented with striae on the stones.

These characteristics indicate that this compact diamicton was deposited subglacially by lodgment (in the meaning of Dreimanis 1976, 1982, Shaw 1985).

MELTOUT TILL

The compact calcareous till is overlain by a light grey, noncompacted, coarser textured diamicton. This middle calcareous till was observed at least at six sites and is the most abundant one in the study area.

It commonly contains interlayered and lenticular silt, sand, gravel, and diamicton strata, as well as percussion and splash structures around boulders and sediment diapirs. Bedding is commonly truncated by dropstones or draped over them. Weakly striated and faceted stones, as well as angular, faulted clasts of sorted sediment and compact till are abundant. Till matrices contain 50% to 65% sand, 35% to 50% silt, under 5% clay, and 20% to 35% carbonate (Table 266.1).

Stones are generally subrounded to subangular and the Paleozoic content is commonly similar to the Precambrian content. Alignment of stones is better developed than in the underlying lodgment till and is parallel to striae on stones within the till.

These data indicate that this unit was deposited subglacially mainly by meltout (in the meaning of Dreimanis 1976, 1982, Shaw 1982, 1983, 1985) but with subglacial stream and subglacial debris flow forming some of the gravelly and diamictic strata.

UPPER LODGMENT TILL

Another fissile carbonate diamicton overlies the meltout till at sites 1, 5, and 6. It is dark grey, fissile, compacted, and stony with matrix compositions approximating 50% sand and silt, with less than 5% clay, and 30% to 35% carbonate (Table 266.1). These are values which may reflect reworking of underlying meltout till.

Pebbles are striated, faceted, and bullet nosed, generally subrounded to subangular, and include clasts of calcareous sand at site 6. Paleozoic clasts dominate over Precambrian in this unit. Pebble alignment is weakly developed but generally agrees with the orientations of shear planes, fissility, till wedges, and striae on stones in the till.

The above data indicate that this unit was also deposited subglacially by lodgment.

SUPRAGLACIAL TILL

Capping the carbonate till package is a generally rusty, noncompacted, coarse-textured diamicton dominated by subangular to angular Precambrian clasts. It is commonly bouldery and the matrix sample analyzed yielded 86% sand and 14% silt but no clay or carbonate (Table 266.1). Stone alignment in this unit is very weak and ambiguous.

It was most likely deposited by supraglacial meltout and commonly covers the ground surface in upland areas (Geddes *et al* 1985). Younger glaciofluvial and glaciolacustrine sediments were studied by Geddes and Bajc (1985a, 1985b) and Geddes *et al* (1985).

GLACIER MOVEMENT AND CLASTIC DISPERSAL

An accurate knowledge of glacier movement directions in the area is essential for developing a strategy for mineral exploration by drill prospecting as well as constructing a depositional model for the tills and determining their source areas. Geddes and Bajc (1985a, 1985b) determined that general ice advance was towards the south-southwest.

LOWER LODGMENT TILL

Some fabric orientations (pebble long axes) in the lower lodgment till display both parallel and transverse clast alignment, indicating that glacier advance was towards the south-southwest. This agrees with the dips of extension fractures and till wedges, as well as striae on stones within the till. Distal Paleozoic lithologies dominate the stones (Table 266.1) but local rocks have been incorporated, including serpentinized peridotite originating from the northeast of Hemlo.

TABLE 266.1. TILL MATRIX AND PEBBLE DATA

Till Unit	Site on Figure 1	Matrix Grain Size (-2.0 mm fraction) %sand	%silt	%clay	Matrix Carbonate (-0.063 mm fraction) %carb	cal/dol	Pebble Data (1-10 cm fraction) roundness	Paleoz/Prec
supraglacial	7	86	14	0	0	0	sa-a	<0.1
upper	1	52	44	04	36	0.9	sr	4.3
	5	46	52	02	34	0.9	sr-sa	3.0
lodgment	6	58	39	03	30	1.0	sr-sa	0.9
middle	1	64	34	02	32	0.8	sr	1.0
meltout	2	61	37	02	32	0.9	sr-sa	1.5
	3	57	43	0	28	0.6	sa-sr	1.3
	4 upper	57	41	02	22	0.8	sr-sa	<0.1
	4 middle	55	43	02	24	0.8	sr-sa	0.1
	4 lower	66	32	02	23	0.8	sr-sa	0.1
	5 upper	48	50	02	32	0.8	sr-sa	1.1
	5 lower	50	50	0	33	0.8	sr-sa	1.1
	7	62	38	0	27	0.5	sr-sa	0.4
lower	2	32	59	09	37	1.3	sr-sa	2.5
	5 top	32	58	10	37	1.3	sr-sa	1.3
lodgment	5 upper	33	56	11	38	1.3	sr-sa	–
	5 middle	34	55	11	37	1.4	sr-sa	1.3
	5 lower	31	56	13	38	1.4	sr-sa	–
	5 bottom	32	56	12	37	1.4	sr-sa	1.4
	7	36	55	09	26	0.9	sr-sa	0.8

cal = calcite, dol = dolomite carb = total calcite and dolomite

Paleoz = Paleozoic lithologies, Prec = Precambrian lithologies

a = angular, sa = subangular, sr = subrounded

MELTOUT TILL

Fabric orientations in the meltout till suggest that glacial advance was to the south-southwest, which is supported by striae on stones in the unit. Paleozoic clasts are commonly the most abundant, but stones of local to intermediate provenance (including peridotite) were also upsheared into the ice when it was actively advancing prior to meltout deposition.

UPPER LODGMENT TILL

In the upper lodgment till, fabric orientations, shear structures, till wedges, and striae on stones indicate that glacial advance was to the south and west. Pebbles are clearly dominated by Paleozoic clasts but do contain some local lithologies as well.

SUPRAGLACIAL TILL

A very weak (random?) fabric was detected in the supraglacial till which is clearly dominated by angular, local clasts derived from granitoid and metavolcanic rocks to the northeast.

SUMMARY

The glaciotectonic and fabric data agree with the ice movement data of Geddes and Bajc (1984a, 1984b) and clearly indicate southwestward advance. Paleozoic, peridotite, and iron formation clasts confirm this since they originated from bedrock sources to the northeast. The Paleozoic pebbles were derived from the James Bay Lowlands, at least 150 km distant. Pebble assemblages indicate that ice advanced southwestward across lithologic contacts rather than parallel to them.

TABLE 266.2. GEOCHEMICAL ANALYSES OF HEMLO TILL SAMPLES (-0.002 mm fraction)

Site	Till Facies	Cu ppm	Ni ppm	Ca %	Pb ppm	Ag ppm	Mo ppm	As ppm	Sb ppm	Ba ppm	Au ppb
1	upper lodgment	38	34	19.3	7	.6	6	2.3	<.2	418	2.9
1	meltout	50	36	19.1	9	.8	4	2.5	<.2	421	9.6
2	meltout	74	61	11.2	12	.4	3	4.0	<.2	701	6.1
2	lower lodgment	39	44	9.89	11	.4	2	3.7	<.2	570	1.7
3	meltout	65	68	4.58	23	.4	2	5.3	<.2	734	24.8
4	meltout (upper)	120	100	9.06	9	.6	6	2.3	<.2	742	9.4
4	meltout (middle)	110	91	11.5	9	.4	6	2.3	<.2	693	7.2
4	meltout (lower)	105	80	12.1	11	.6	6	2.7	<.2	681	5.9
5	upper lodgment	48	46	14.8	13	.8	6	4.3	<.2	481	4.4
5	meltout	41	45	15.6	12	.4	5	3.7	<.2	465	11.2
5	meltout	50	48	13.0	16	.4	3	5.0	<.2	467	8.0
5	lower lodgment (top)	25	46	12.2	10	.4	5	1.2	<.2	574	1.6
5	lower lodgment (upper)	25	44	12.1	8	.4	6	1.8	<.2	558	1.7
5	lower lodgment (middle)	10	20	13.1	3	.4	2	1.9	<.2	558	2.2
5	lower lodgment (lower)	10	20	12.9	4	.6	3	1.8	<.2	540	1.4
5	lower lodgment (bottom)	10	20	12.6	3	.6	2	1.9	<.2	560	2.4
6	upper lodgment	62	43	18.1	8	.6	2	2.5	<.2	473	2.3
7	supraglacial	200	130	.86	40	.4	3	5.2	<.2	669	57.3
7	meltout	220	93	2.21	25	.4	3	5.2	<.2	724	17.1
7	lower lodgment	85	65	3.82	13	.4	5	3.7	<.2	625	3.2

GEOCHEMICAL GLACIAL DISPERSAL

Atomic absorption analyses of the -0.002 mm fraction in till matrices for nine metals and arsenic are presented in Table 266.2. This size fraction was chosen because it most accurately reflects pre-weathering proportions of metals in the till matrix (Shilts 1975, 1984).

The supraglacial meltout till is generally richest in metals, especially gold, whereas the calcareous tills contain lesser amounts of metals, with the exception of calcium. Meltout till is generally richer in metals than the lodgment facies, but has lesser matrix carbonate. The relationship between metal content and matrix carbonate is demonstrated in Figure 266.2 for four significant metals, in general, as matrix carbonate increases, metal content decreases. This trend reflects relative dilution of metals of local to intermediate provenance by distal carbonate matrix during glacial transport and deposition. Supraglacial till has little or no carbonate matrix and better reflects the local bedrock geochemistry.

DEPOSITIONAL MODEL AND GLACIAL HISTORY

The entire till sequence in the Hemlo area can be explained by one glacial advance over uplands to the northeast. The carbonate tills are probably the result of glacial deposition in the lee sides of the uplands (Figure 266.1) resulting in deposition of englacial debris that was downsheared to the basal zone as the glacier temporarily experienced extending flow, and later, stagnation.

The depositional model depicted in Figure 266.3 bears similarities to that proposed by Gillberg (1965) in Sweden, although Shilts (1973) has also reported on upland lee side glacial deposition in Quebec. A hypothesis of ice behaviour and till deposition is presented below (Figure 266.3).

Glacier ice advancing from the north-northeast met the stoss side of the upland and experienced local compressional flow which was diverted around it, as well as inducing upshearing of glacial debris, and eroding the local bedrock and depositing Geddes' (1984a, 1984b, 1984c), Geddes and Bajc's (1985a, 1985b), and Geddes' *et al.* (1985) basal noncarbonate till. The englacial zone overrode the retarded basal ice and continued the stoss side upshearing of local debris to the supraglacial position (above englacially transported distal debris, Figure 266.3). It then advanced over the upland while experiencing downshearing of its debris during extending flow. This resulted in lodgment of englacial debris on top of the basal noncarbonate till, on the lee side of the upland.

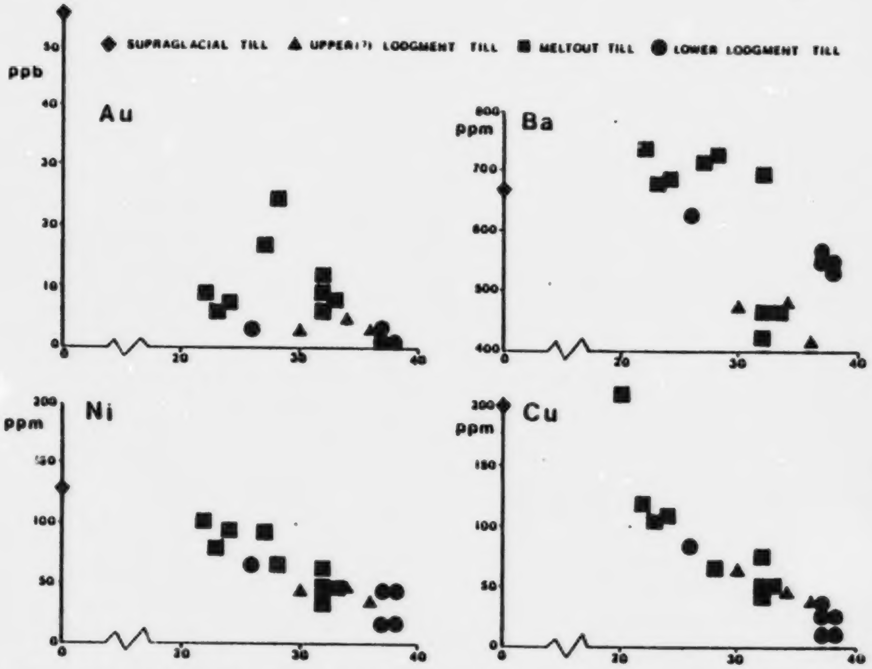

Figure 266.2. Geochemical comparison of significant metals in Hemlo till matrices (-0.002 mm fraction) with matrix carbonate (-0.063 mm fraction).

After the glacier reached its maximum extent, it probably stagnated in the Hemlo area where the bulk of the glacial debris was deposited by subglacial meltout. This is supported by the various late glacial ice disintegration features in the area (Geddes and Bajc 1984a, 1984b). The upper till probably represents a late reactivation of the glacier during general downwasting and further deposition of englacial debris as lodgment till.

Finally, upland stoss side debris that was upsheared to the supraglacial position was lowered to the surfaces of the underlying calcareous meltout and lodgment tills by supraglacial meltout.

ECONOMIC AND ENVIRONMENTAL ASPECTS

The above results and interpretations indicate that an understanding of till genesis, stratigraphy, and ice movements are important for mineral exploration strategies and environmental considerations. Some recommendations are presented below for the Hemlo area.

DRIFT PROSPECTING

The supraglacial meltout till, and probably Geddes' basal noncarbonate till, are best to sample in overburden drilling programs.

They comprise material that has been transported for relatively short distances (mainly derived from uplands less than 20 km upglacier; Figure 266.1) and are, therefore, most likely to contain well defined dispersal fans of ore anomalies which may be traced back to source (c.f. Shilts 1976, 1984). This is exemplified by the relatively high gold value in the supraglacial till, which occurs within an active gold mining area.

The calcareous tills, however, are detrimental to drift prospecting because they contain mainly distally transported materials (some from at least 150 km

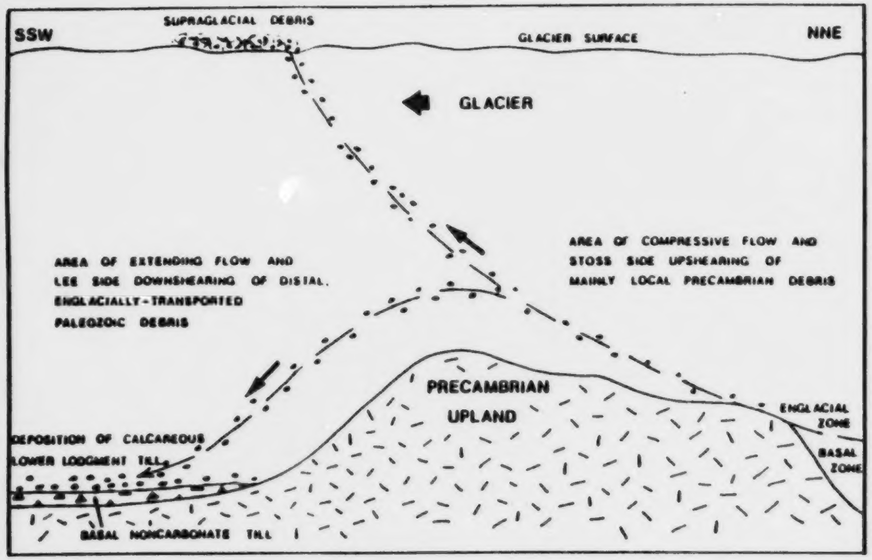
SSW
SUPRAGLACIAL DEBRIS
GLACIER SURFACE
NNE
GLACIER
AREA OF EXTENDING FLOW AND LEE SIDE DOWNSHEARING OF DISTAL, ENGLACIALLY-TRANSPORTED PALEOZOIC DEBRIS
AREA OF COMPRESSIVE FLOW AND STOSS SIDE UPSHEARING OF MAINLY LOCAL PRECAMBRIAN DEBRIS
PRECAMBRIAN UPLAND
ENGLACIAL ZONE
BASAL ZONE
DEPOSITION OF CALCAREOUS LOWER LODGMENT TILL
BASAL NONCARBONATE TILL

Figure 266.3. Schematic model of the glacier advancing over an upland northeast of Hemlo. Not to scale

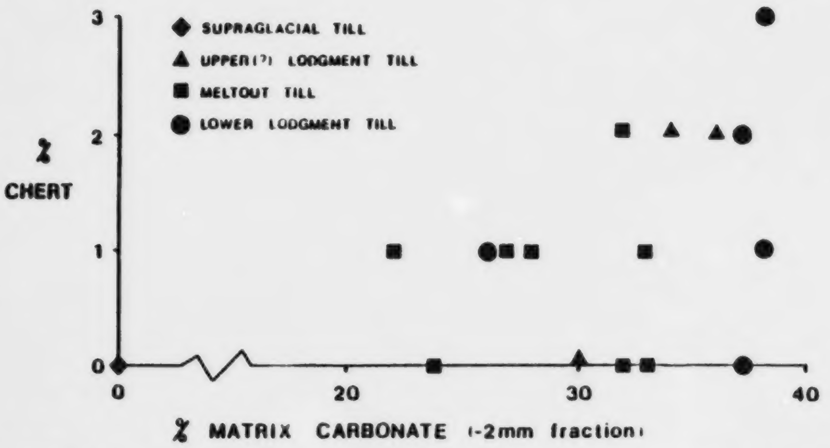

Figure 266.4. Comparison of chert pebble content in Hemlo tills with till matrix carbonate (-0.063 mm fraction)

away) which mask glacially dispersed ore of local to intermediate provenance. Any disperal fans within the calcareous tills will probably be too diffuse to recognize, or to successfully trace anomalies back to source, because ore values are near background levels this far downglacier from distal ore sources.

AGGREGATE QUALITY

Gravel in the Hemlo area should be good for construction purposes. The highest chert content (which can cause hydration and cracking problems in southern Ontario concrete) was only 3% in the till samples collected, and generally increases with matrix carbonate (Figure 266.4). Several samples contained no chert. Associated outwash deposits should also contain low amounts of chert as they were probably derived from the same glacier.

However, rolled amphibolite, granitoid, and gneissic stones are relatively abundant in a few places and may be problematic for aggregate usage.

ACID RAIN

The calcareous tills should be excellent buffers. They are almost as calcareous as those overlying carbonate bedrock in southern Ontario where till matrix carbonate would attain a maximum.

Map unit 3b of Geddes and Bajc (1984a, 1984b) is the least susceptible to acid rain, although some glaciolacustrine deposits are also calcareous. Thus a map of acid rain susceptibility could be constructed based on the matrix carbonate of the various sediment units in the area, such as that attempted by Woods (1985, p.45).

Lakes within areas of calcareous glacial drift are more alkaline than those without and also serve as buffers (Woods 1985; Coker and Shilts 1979).

TAILINGS DAM CORES

The calcareous lodgment tills serve well as low-permeability cores with high capacity for buffering acidic mine tailings. Lac Minerals used the lower lodgment till for this purpose, the excavation of which provided the exposure at site 5.

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R.S. Geddes (Engineering and Terrain Geology Section, Ontario Geological Survey) provided invaluable logistical and scientific support throughout the course of this study. E.V. Sado (Engineering and Terrain Geology Section, Ontario Geological Survey) suggested the project and was generous with advice and support. G.O. and S.L. Brown (Department of Geology, University of Western Ontario) ably performed field and laboratory duties. S.L. Brown and J.-A. Potter (Department of Geology, University of Western Ontario) assisted in drafting the diagrams. Research was funded by the Ontario Geoscience Research Grant Program.

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Appendix 2:

Genesis of carbonate till in the lee sides of Precambrian Shield uplands, Hemlo area, Ontario. reprint by S.R. Hicock

Genesis of carbonate till in the lee sides of Precambrian Shield uplands, Hemlo area, Ontario

STEPHEN R. HICOCK
Department of Geology, The University of Western Ontario, London, Ont., Canada N6A 5B7

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Near Hemlo, Ontario, highly calcareous till is confined to areas located downglacier from Precambrian uplands, at least 150 km from the Paleozoic – Precambrian boundary. It comprises subglacial meltout till between lodgment tills, and the calcareous package overlies noncalcareous basal till (not studied) and underlies noncalcareous supraglacial meltout till. The tills can be distinguished by textural, carbonate, and clast compositions. Glaciotectonic deformations, stone fabrics and striae, and stone provenance from the tills, as well as erosional and depositional landforms, indicate that ice advanced to the south – southwest across bedrock contacts and over Precambrian uplands.

Deposition of all five tills can be explained with one glacial event. As the Late Wisconsinan margin of the Laurentide ice sheet advanced against uplands about 20 km northeast of Hemlo it experienced compressive flow while depositing the noncalcareous basal till. Upshearing of stoss-side local debris high into the ice also occurred as englacial ice overrode the slowed basal zone. Once over the upland, englacial ice assumed extending flow, and downshearing of distal debris, which was deposited as calcareous lodgment till on the lee sides of uplands. After the glacial maximum, the glacier ceased internal movement and subglacial meltout till was laid down. A late reactivation of the ice deposited the upper lodgment till and final stagnation formed the supraglacial meltout till.

Le till fortement calcaire près d'Hemlo (Ontario) est limité aux aires localisées en aval du glacier à partir des terrains élevés d'âge précambrien, et éloignées d'au moins 150 km de la frontière du Paléozoïque – Précambrien. On observe un till de fonte sous-glaciaire entre les tills de fond, et les matériaux calcaires recouvrent un till basal non calcaire (pas étudié) et sont sous-jacents à un till de fonte supraglaciaire non calcaire. Les tills diffèrent par leur texture, leur teneur en carbonate, et la nature de leurs fragments. Les déformations glaciotectoniques, les fabriques des pierres et les stries, et la provenance des pierres incorporées dans les tills, ainsi que les formes de terrains dues à l'érosion ou à l'accumulation des matériaux, révèlent une progression du glacier vers le sud-sud-ouest traversant les contacts du substrat rocheux et se répandant sur les terrains élevés du Précambrien.

La formation des cinq tills peut être expliquée par un seul événement glaciaire. Au Wisconsinien supérieur, lorque la marge de l'inlandsis laurentidien se déplaçait contre les terrains élevés du Précambrien, à environ 20 km au nord-est d'Hemlo, l'écoulement fut soumis à des compressions durant la sédimentation du till basal non calcaire. La glace intraglaciaire qui avançait plus rapidement que celle de la zone basale a induit un cisaillement ascendant dans les débris localisés du côté de la pente douce, haut dans la zone glaciale. Une fois le terrain élevé escaladé, la glace intraglaciaire s'est largement répandue et les débris distaux appartenant au till de fond noncalcaire sur les côtés abrités des terrains élevés exhibent un cisaillement descendant. Après l'avancée culminante de la glace, le mouvement interne du glacier a cessé et le till de fonte seus-glaciaire fut déposé. Une réjuvénation de l'avancée glaciaire a déposé le till de fond et ensuite durant une période de stagnation il y a eu dépôt du till de fonte supraglaciaire.

[Traduit par la revue]

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Introduction

Most tills on the Canadian Shield comprise noncalcareous, coarse-textured crystalline materials that are locally derived (Scott 1976). In the gold-rich Hemlo area of Ontario, however, till rich in carbonates (in both the clast and matrix fractions) was encountered that was derived mainly from Paleozoic rocks underlying the James Bay Lowlands at least 150 km to the north – northeast (Fig. 1 inset). Part of the till is highly compacted with glaciotectonic structures and yet cannot be explained by normal lodgment deposition of mainly local materials. This paper investigates the glacial entrainment, transport, and mode of deposition of this unusual till in order to explain its occurrence far downglacier from the Paleozoic – Precambrian boundary.

Fieldwork was done on mine excavations, road cuts, and gravel pits in July, 1985. Seven key exposures were studied in detail for stratigraphic and structural relations of sediment units, and samples were collected for grain size, carbonate, pebble lithology, geochemical, and heavy mineral analyses in order to characterize the units and determine their modes of deposition and provenance. Granulometric analyses were performed by the hydrometer – sieve method of the American Society for Testing and Materials (1972), using 0.002 and 0.063 mm as the clay – silt and silt – sand boundaries, respectively; carbonate analyses, after the method of Dreimanis (1962); and heavy mineral separations, using liquid sodium polytungstate (specific gravity 2.90). Computer analyses of stone long axis orientations (fabrics) were accomplished with the method of Mark (1973, 1974).

Till criteria and terminology used in this paper follow the system of the International Union for Quaternary Research's Commission on Genesis and Lithology of Glacial Deposits as summarized by Dreimanis (1982). The terms upshearing and downshearing are used in this paper with a general meaning of glacial transport upwards or downwards (with or without ice displacement) along slip lines of maximum shear stress as described by Nye (1952).

Physical setting and previous work

In the Hemlo area, uplands dominate the northern part and low-lying areas containing abundant lakes, the southern part, with relief up to 220 m (Fig. 1). The area is underlain by a structurally complex sequence of Archean lithologies, including metavolcanic (amphibolite, basalt), metasedimen-

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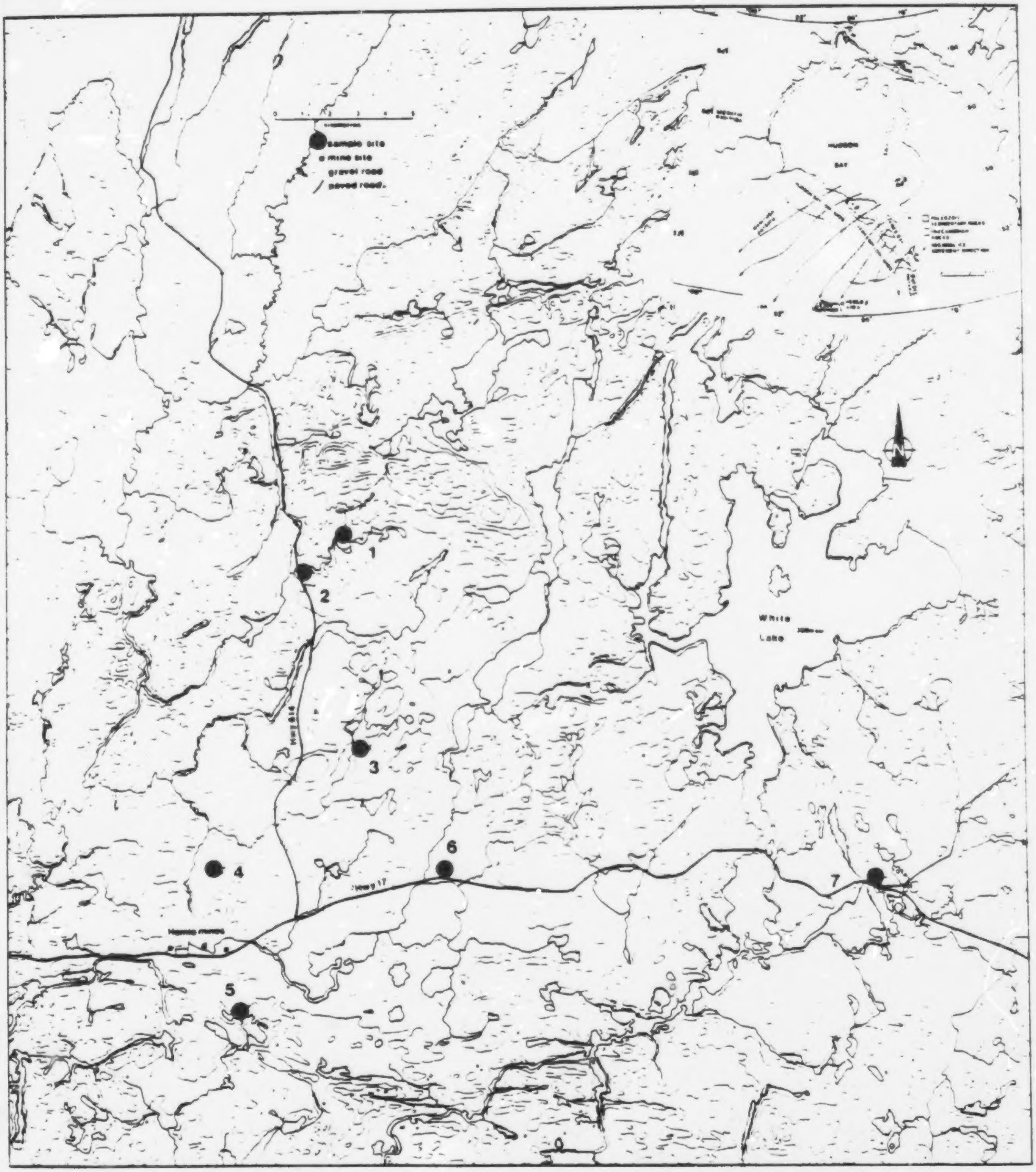

0 1 2 3 4 5
sample site
mine site
gravel road
paved road.
HUDSON BAY
White Lake
Hwy 614
Hwy 17
Hemlo mines
1
2
3
4
5
6
7
N

FIG. 1. Topographic and location maps of the study area. Inset is a map of regional ice flow paths and Paleozoic source rocks for Hemlo drift (modified after Shilts 1980). Contour interval is 30 m.

tary (schist, marble, sandstone, quartzite), granitoid plutonic (mainly granodiorite), and gneissic rocks (presented later in Fig. 5*b*). Diabase dykes have intruded other lithologies ubiquitously; rare patches of iron formation and ultramafic rocks (peridotite, serpentinite) can be found.

Quaternary studies north of Lake Superior have included those of Farrand (1962), who concentrated on landforms, glacial lakes, their outlets, and glacioisostatic rebound, Zoltai

(1965*a*, 1965*b*, 1967), and Boissonneau (1966), who completed surficial geology maps and recognized the carbonate-rich till. Also, Coker and Shilts (1979) in a lake geochemistry study generally described the till, Geddes and Kristjansson (1986) and Hicock (1986) discussed its applications to the mining industry, and Karrow and Geddes (1987) explained its effects in northern Ontario on mollusc radiocarbon dating and exploration strategies. Fortescue and Geddes (1983), Geddes (1984*a*, 1984*b*, 1984*c*, 1985), Kristjansson (1984), Geddes and Bajc (1985*a*, 1985*b*), Geddes *et al.* (1985), Woods (1985), and White (1986) have described carbonate till in more detailed mapping and case studies. Gartner and McQuay (1979, 1980) provided engineering and terrain studies of the area, Cowan (1976) an aggregate inventory, and Shilts (1980) and Dyke *et al.* (1982) documented general glacier flow patterns in the area beneath the central part of the Laurentide ice sheet.

Pleistocene sediments in the area appear to have been deposited during the Late Wisconsinan Substage. The oldest radiocarbon date is 9380 ± 150 years BP (GSC-287; Zoltai 1965*a*) from wood in late-glacial lake deposits.

Character and stratigraphy of Hemlo tills

The oldest sediment encountered in mine excavations and drillholes is a locally derived subglacial till observed by Geddes (1984*a*, 1984*c*), Geddes *et al.* (1985), and Geddes and Kristjansson (1986); it was not encountered in the sections studied by the author.

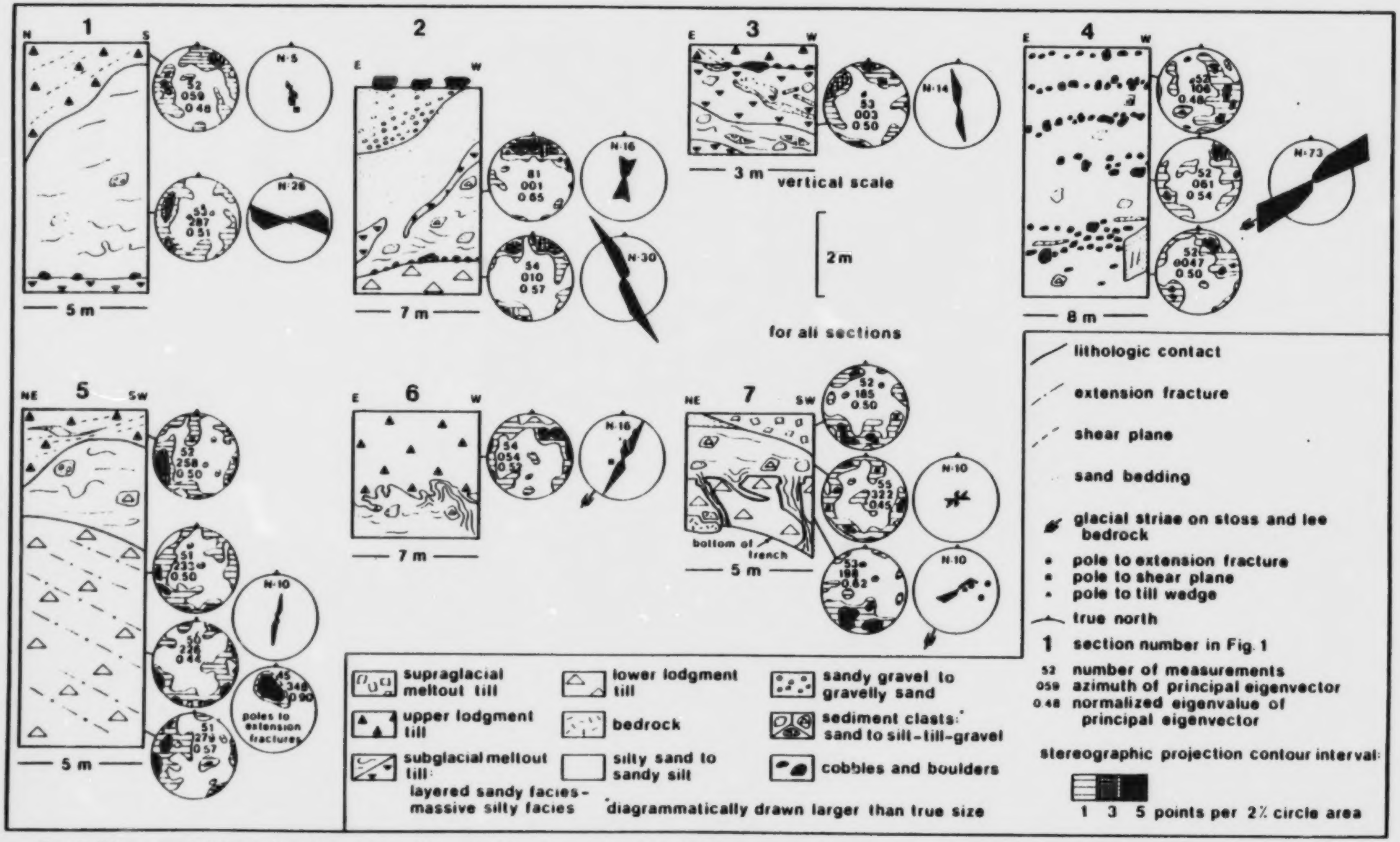
The overlying unit occurs in three of the seven sections studied, which are presented diagrammatically in Fig. 2 and pictorially in Fig. 3. It comprises dark grey, compact, calcareous diamicton, which is at least 5 m thick at site 5. The diamicton is fissile, stony, and contains striated, faceted, and bullet-nosed stones, as well as rare pockets of sand at sites 2 and 7. Diamicton matrix (−2.00 mm) comprises about 35% sand, 55% silt, 10% clay (Fig. 4*a*), and 35−40% total carbonates (calcite and dolomite; Fig. 4*b*). Stones are generally subrounded to subangular and dominated by Paleozoic and Proterozoic lithologies, indicating distal glacial transport (Fig. 4*c*). Parallel and transverse alignment of stones in the diamicton, as well as extension fractures (Figs. 3*a*, 3*b*) and diamicton wedges formed penecontemporaneously with deposition (cf. Hicock and Dreimanis 1985), are consistently oriented with striae on the stones (Fig. 2). The above characteristics indicate that this compact diamicton was deposited subglacially under moving ice by lodgment as defined by Dreimanis (1976, 1982) and Shaw (1985). The diamicton is therefore called lodgment till.

The compact calcareous till is overlain by a light grey, noncompacted, coarser textured diamicton. This middle calcareous diamicton is the most abundant one in the study area and was found at every site (Fig. 2). At the two sites where the contact was clearly observed it was sharp (marked by a pebble pavement at site 2). The middle unit commonly contains interlayered and lenticular silt, sand, gravel, and massive silty diamictic strata, as well as sag and squeeze structures under boulders (Fig. 3*c*), cuspate dewatering structures, and even sediment diapirs. Bedding is commonly truncated by dropstones or draped over them. Weakly striated and faceted stones, as well as angular, faulted clasts of sorted sediment and compact till (Fig. 3*d*), are abundant. At section 4 a large angular block of sorted sediment (Fig. 2) is preserved with faulted bedding intact, which probably precludes deposition involving subglacial shearing (Shaw 1982, 1985). Diamicton matrices contain 50−65% sand, 35−50% silt, under 5% clay (Fig. 4*a*), and 20−35% carbonate (Fig. 4*b*). Stones are generally subrounded to subangular and the distal content varies in pebble samples but is commonly similar to the Archean content (Fig. 4*c*). Alignment of stones is parallel to striae on stones within the diamicton.

The above data indicate that this unit was formed (in the meaning of Shaw 1982, p. 1548) passively under and within inactive ice, mainly by meltout as defined by Dreimanis (1976, 1982) and Shaw (1979, 1982, 1985), but with subglacial to englacial streams and debris flows forming some of the gravelly and diamictic strata, respectively. Pressure melting and lodgment probably also participated in the formation of part of the unit, prior to final deposition (in the meaning of Shaw 1982, p. 1548), since boulder pavements were found within it at site 4 (Figs. 2, 3*e*). Pavement stone fabrics and striae are well oriented parallel to striae on roches moutonnées beside the section, implying their alignment by moving ice. The pavements probably formed by lodgment superimposed on successive slabs of stationary debris-rich basal ice that were melting. Thus, final deposition of the pavements, and interpavement glacial debris, was by subglacial meltout. Section 4 may represent a transition from lodgment to subglacial meltout processes as internal movement within the basal zone of the glacier sporadically ceased.

Another fissile carbonate diamicton overlies the meltout till at four sites (Fig. 2). It is dark grey, fissile, compacted, stony, and its lower contact is commonly sharp. Matrix compositions comprise about 50% each of sand and silt, with less than 5% clay (Fig. 4*a*), and 30−35% carbonate (Fig. 4*b*), values which are intermediate between underlying meltout and lodgment tills. Pebbles are striated, faceted, and bullet-nosed, generally subrounded to subangular, and include clasts of calcareous sand at site 6. Distal clasts also dominate over Archean in this unit (Fig. 4*c*). Pebble alignment is weakly developed but generally agrees with the orientations of shear planes (Fig. 3*f*), fissility, till wedges (Fig. 3*g*), and striae on stones in the diamicton. Diapiric structures occur below the diamicton's irregular but sharp contact with its substratum at site 6 (Fig. 3*g*). The structures are very similar to those described in Poland by Ruszczyńska-Szenajch (1983), who attributed them to lodgment of the till and penecontemporaneous glaciotectonic deformation of the substratum. The above data indicate that this unit was also deposited subglacially by lodgment.

Capping the carbonate till package is generally rusty, noncompacted, coarse-textured diamicton dominated by subangular to angular Archean clasts (Fig. 3*h*). It is commonly bouldery and the matrix comprises about 85% sand and 15% silt (Fig. 4*a*). No carbonate was detected in the matrix (Fig. 4*b*) and the pebble fraction is overwhelmingly dominated by Archean lithologies (Fig. 4*c*). Stone alignment in this unit is very weak and ambiguous. This unit was most likely deposited by supraglacial meltout and commonly covers the ground surface in upland areas (Geddes *et al.* 1985; Geddes and Kristjansson 1986). The few striated, subrounded distal clasts in the unit were probably upsheared to or near the supraglacial position of the transporting glacier prior to lowering of its debris cover to ground level during deposition by supraglacial meltout. Younger glaciofluvial and glaciolacustrine sediments were studied by Geddes and Bajc (1985*a*, 1985*b*) and Geddes *et al.* (1985) and are not dealt with here.


1
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S
5 m
52
059
0.48
N·5
53
287
0.51
N·26
2
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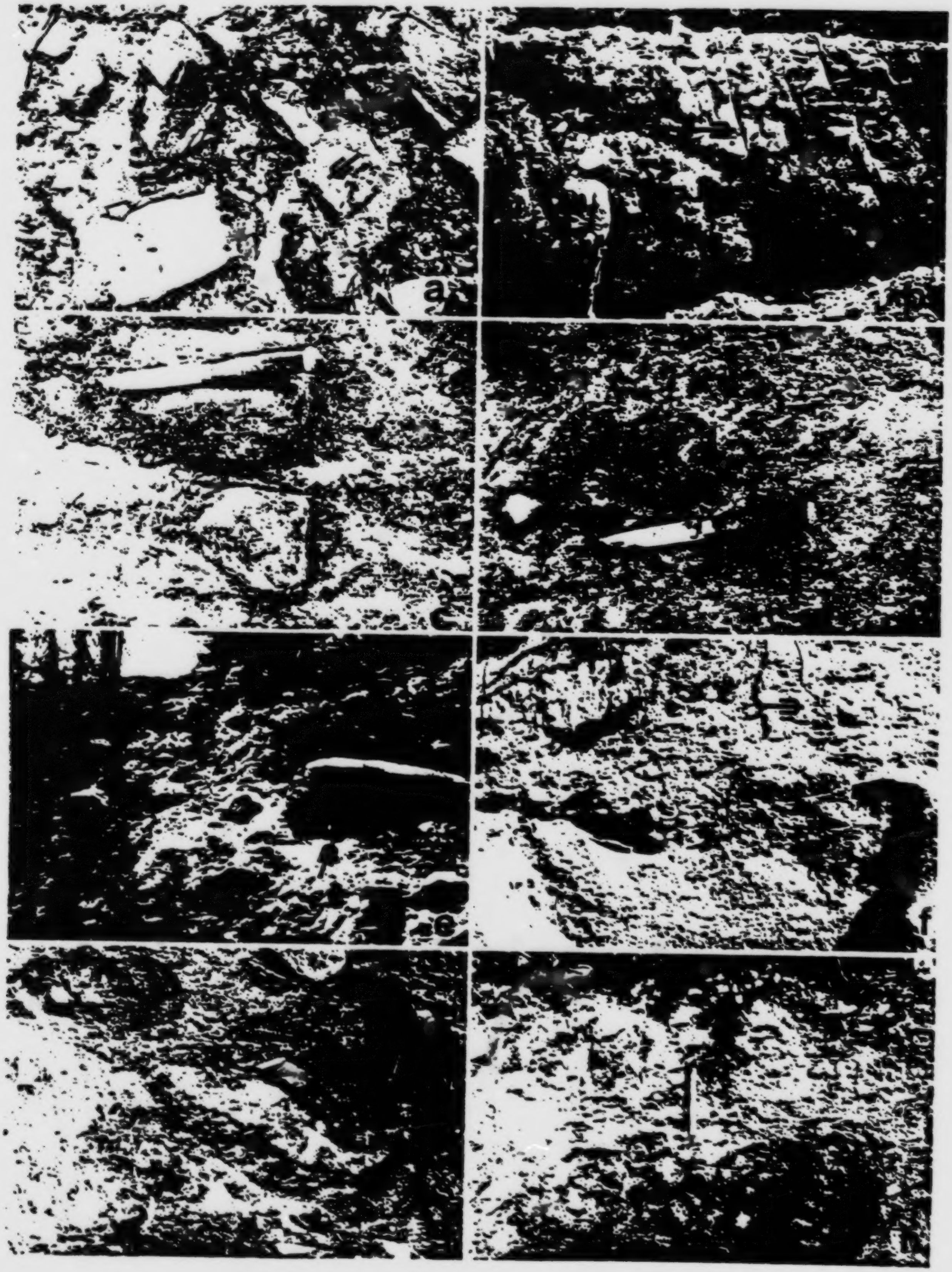
W
7 m
81
001
0.65
N·16
54
010
0.57
N·30
3
E
W
3 m
53
003
0.50
N·14
vertical scale
2m
for all sections
4
E
W
8 m
52
106
0.48
52
061
0.54
52
047
0.50
N·73
5
NE
SW
5 m
52
258
0.50
51
233
0.50
50
226
0.44
51
279
0.57
N·10
45
348
0.90
poles to extension fractures
6
E
W
7 m
54
054
0.52
N·16
7
NE
SW
bottom of trench
5 m
52
185
0.50
55
322
0.45
53
198
0.62
N·10
N·10
lithologic contact
extension fracture
shear plane
sand bedding
glacial striae on stoss and lee bedrock
pole to extension fracture
pole to shear plane
pole to till wedge
true north
1 section number in Fig. 1
52 number of measurements
059 azimuth of principal eigenvector
0.48 normalized eigenvalue of principal eigenvector
stereographic projection contour interval:
1 3 5 points per 2% circle area
supraglacial meltout till
upper lodgment till
subglacial meltout till: layered sandy facies - massive silty facies
lower lodgment till
bedrock
silty sand to sandy silt
sandy gravel to gravelly sand
sediment clasts:* sand to silt-till-gravel
cobbles and boulders
*diagrammatically drawn larger than true size

FIG. 2. Diagrammatic lithostratigraphic sections with contoured equal-area, lower hemisphere, stereographic projections of stone long (a) axes. Mirror image, two-dimensional rose diagrams of striae on top surfaces of stones are presented beside the stereographic projections at the approximate level of measurement within the section.


a
b
c
e
f
h

In summary, the till units can be differentiated by their matrix textural and carbonate compositions, and their clast lithologies (Fig. 4). The lower lodgment till is characterized by a finer and more calcareous matrix with calcite/dolomite (*c*/*d*) ratios commonly higher than 1, and it is dominated by Paleozoic limestone clasts. Meltout till tends to be sandier, less calcareous with *c*/*d* ratios commonly less than 1, and more equal proportions of distal and Archean stones. The upper lodgment till is intermediate between the lower lodgment and the meltout units in matrix characteristics, probably reflecting erosion and incorporation of the meltout by overriding glacier ice. Supraglacial till is much coarser, noncalcareous, and comprises almost entirely Archean clasts.

Glacier advance direction

An accurate knowledge of glacier movement directions in the area is essential for developing a depositional model for the tills and determining their source areas for mineral exploration purposes. A summary of ice advance directions is presented in a kineto-stratigraphic diagram (Fig. 5*a*; net (averaged) arrow azimuths are estimated from various criteria indicated), which indicates that ice advance was generally towards the south–southwest and agrees with Geddes and Bajc (1985*a*, 1985*b*).

In the lower lodgment till fabric, orientations of pebble long (a) axes are not strongly developed but commonly display both parallel and transverse clast alignment and indicate general glacier advance towards the south–southwest. Sand-filled extension fractures and till wedges within the unit at sites and 7 (formed penecontemporaneously with till deposition; Fig. 3*b*) dip downglacier (cf. Broster *et al.* 1979; Hicock and Dreimanis 1985; Åmark 1986) and support this trend, as do striae on the surfaces of stones within the till. However, topography also caused local variation in this general trend, as well as fabric alignment, as demonstrated at site 5 (Figs. 2, 5*a*).

At site 5 the swings in direction from south–southwest to southwest to south–southeast (given by fabrics measured stratigraphically higher in the till, as well as striae on stone surfaces and the dips of till fractures) may be explained by local compressive flow against a bedrock ridge. The ridge is at least 60 m high, occurs just downglacier from the site, and is elongated west–northwest and east–southeast (Fig. 1). Glacier ice probably advanced to the south–southwest until it encountered the ridge, whereupon it experienced compressive flow, creating local flow divergence in an attempt to overcome the ridge, and developed a noticeable transverse stone fabric (eigenvalue 0.57). Boulton (1970, p. 239) and Krüger and Thomsen (1981, p. 22) also documented transverse fabrics in lodgment tills formed under local compressive flow on the stoss sides of bed obstructions. Stanford and Mickelson (1985) explained this by clasts rotating under compressive flow in order to reduce the ice velocity gradients across them. Indeed, clast rotation at this site is evidenced by many bullet-nosed stones found in the middle part of the till section but in a variety of orientations.

Striae on the top surfaces of stones consistently trend north–northeast and south–southwest at all three levels in the lower lodgment till at site 5 (Fig. 2). This may reflect lodgment and alignment of clasts in matrix during divergent lateral flow along the ridge, immediately followed by (and alternating with) erosion and clast striation as the glacier sporadically slid over them towards the ridge. By this reasoning the clast striae may still record the main ice movement direction. In response to lateral flow, a bimodal stone fabric developed both transverse and parallel components, resulting in a misleading eigenvalue (0.44) and eigenvector (226°) that fall between the modes (Woodcock 1977; Dowdeswell *et al.* 1985; Dowdeswell and Sharp 1986). Eventually a slightly stronger parallel fabric (eigenvalue 0.50) developed as the ridge diverted the glacier's path southwestward. Finally, extension fractures penetrated the entire lower lodgment till section at site 5 (Fig. 3*b*) and were probably formed late during till deposition and subglacial drag as ice thickness built up behind the ridge and glacier flow was diverted to the south–southeast before overriding it.

At site 2 both stone striae and fabric trend northwest–southeast and probably represent a local ice flow divergence by a spur ridge extending southward from a prominent upland plateau to the north of the site (Fig. 1). At site-7 fabric, stone striae, extension fractures, till wedges, and striae on a bedrock step are consistent with southwest flow downglacier from a northwest–southeast trending bedrock ridge (Fig. 1).

Stones in the meltout till are generally more consistently oriented (fewer parallel–transverse combinations) than in the lower till and suggest that glacier advance was to the south–southwest (with some local variations). This is supported by striae on stones in the meltout unit (Fig. 2). The more consistent fabrics imply that ice movement just prior to meltout deposition was not as affected by local topography as ice flow just prior to deposition of the lower lodgment till.

In the upper lodgment till, fabric orientations are not strongly developed but exhibit subtle parallel and transverse trends and indicate that glacial advance was generally to the southwest (Figs. 2, 5*a*). At site 1 the fabric is probably mainly transversely oriented and local ice advance appears to have been towards the southeast there, which is consistent with bedrock striae related to the Cochrane readvance in northern Ontario (Boissonneau 1966; Shilts 1980). Shear planes at site 5 (Fig. 3*f*), fissility at site 1, and sheared sand lentils at site 6 rise downglacier (cf. Hicock and Dreimanis 1985), while till wedges into underlying sand dip downglacier at site 6 (Figs. 2, 3*g*; Hicock and Dreimanis 1985). Striae on roches moutonnées at site 6 agree with the dip direction of the till wedges. In the supraglacial till at site 7, a poorly developed fabric plunges shallowly southward.

FIG. 3. Hemlo till facies and representative structures. Striae symbols indicate approximate ice advance direction in the photo. Knife is 20 cm long. (*a*) Quarried and fractured bedrock steps infilled with till at site 7. The striated block (arrow) has been displaced and the void infilled with till (under the knife). (*b*) Extension fractures in lower lodgment till at site 5. The central fracture is filled with sand and silt; near-vertical grooves are diesel shovel teeth marks. (*c*) Sediment layering and squeeze structure between stones in subglacial meltout till at site 3. The lower stone has also depressed underlying strata. (*d*) Lodgment till clast has deformed surrounding sediment within subglacial meltout till at site 7. (*e*) Boulder–cobble pavements in subglacial meltout till at site 4. Two boulders (arrowed) are shown that were fractured and slightly displaced during lodgment of a pavement prior to its final deposition by meltout. (*f*) Tension gash infilled with sand (above knife), and rising shear planes, in upper lodgment till at site 5. (*g*) Exposed till wedge of upper lodgment till injected into subglacial meltout unit at site 6. The view is through the plane of the wedge into subglacial meltout material on its downglacier side (under the knife). Diapiric structures also appear in the underlying meltout unit beside the wedge. (*h*) Angular clasts in rusty, sandy, supraglacial meltout till between sites 1 and 2. Pick is 42 cm long.

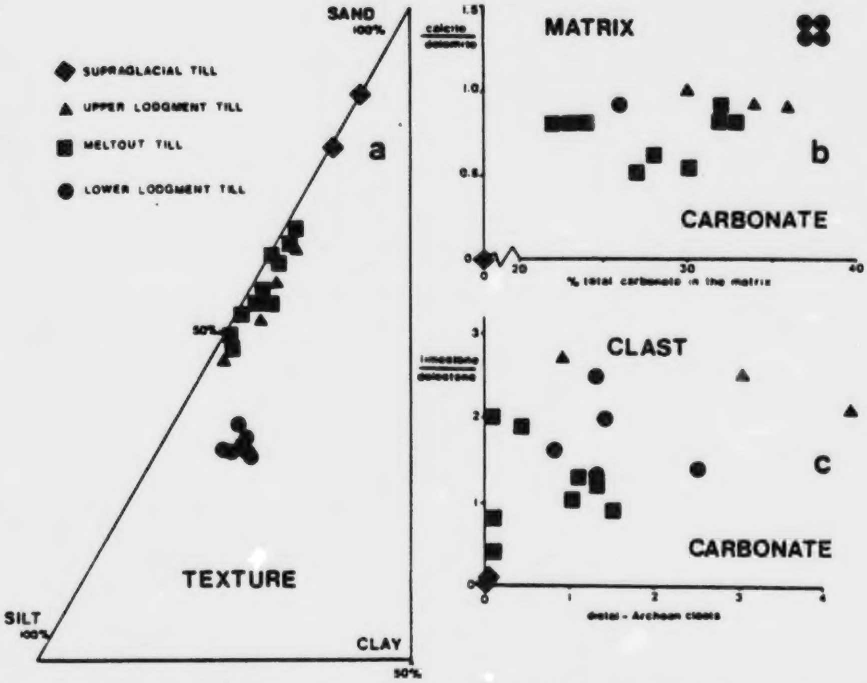


FIG. 4. Laboratory data summary: (*a*) textural ternary; (*b*) matrix carbonate; and (*c*) clast carbonate. Matrix and clast carbonate data from the upper lodgment till at site 3 were not plotted because of carbonate leaching in the B soil horizon.

Till provenance

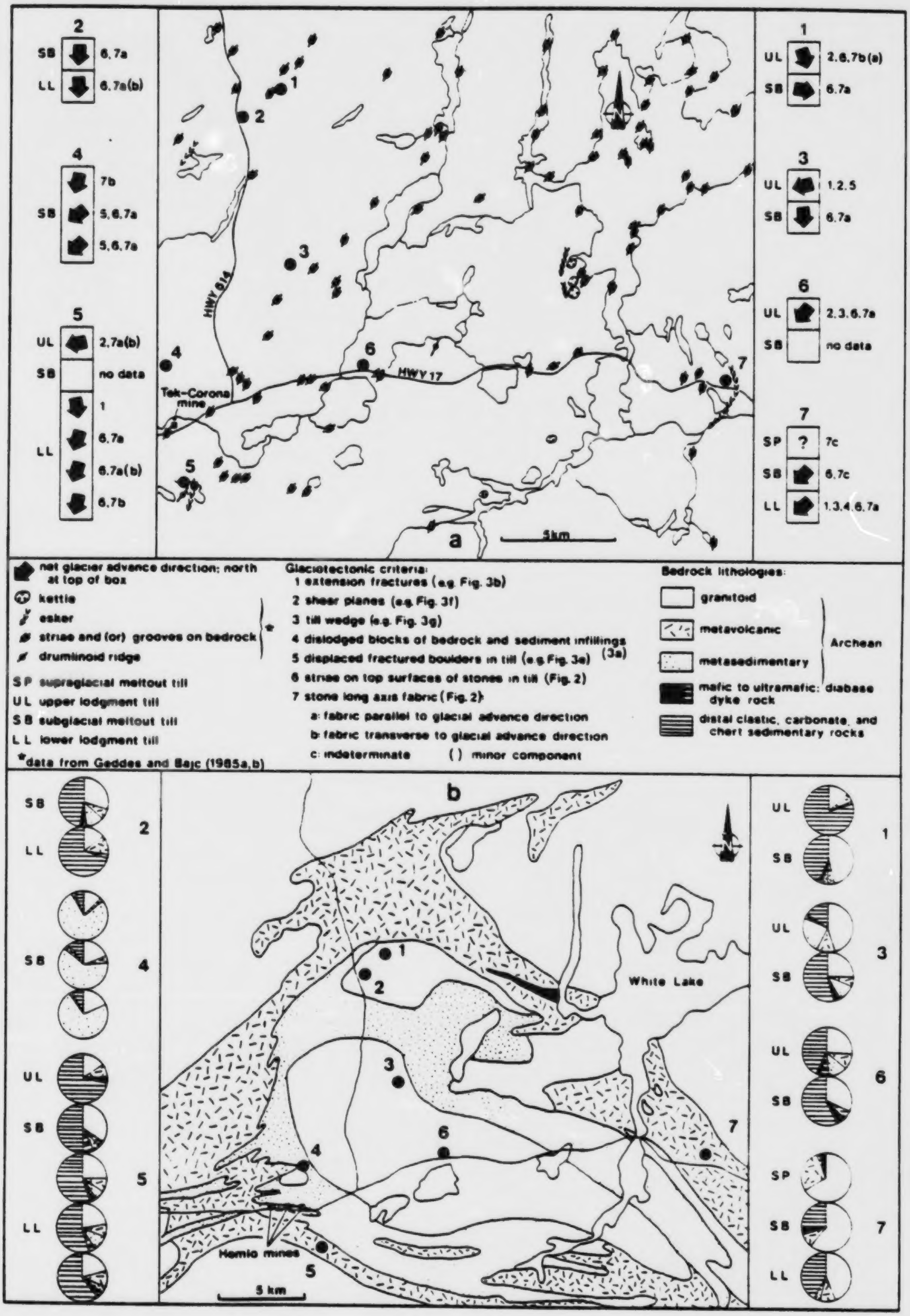
Besides the ice movement indicators summarized in Fig. 5*a*, determination of source areas of the till materials is valuable information for checking advance directions, as well as interpreting modes of glacial transport and deposition. It is obvious that the Paleozoic and Proterozoic clasts must have been distally derived from the James Bay Lowlands and eastern Hudson Bay, respectively (Fig. 1 inset), and that ice advance was southward from those source areas (Shilts 1980; Geddes 1984*c*; Kristjansson 1984; Geddes *et al.* 1985; Geddes and Kristjansson 1986). However, in addition to the obvious distal provenance, a study of the Archean lithologies in the till samples may help to refine the interpretation of ice movements in the Hemlo area and supplement the glaciotectonic data presented above.

Pebble lithologic data is presented stratigraphically as pie diagrams in Fig. 5*b*. Stones ranging from 1 to 10 cm in diameter were collected and many thin-sectioned and identified under transmitted polarized light until sufficient confidence was gained to identify the remainder under a binocular microscope. The clasts were then subdivided into six categories reflecting the bedrock lithologies around the study area: Archean granitoid (mainly granodiorite and granite gneiss), metavolcanic (amphibolite and metabasalt), metasedimentary (intermediate-grade schists and quartzite), diabase dyke rock, ultramafic (periodotite and serpentinite), and distal sedimentary rocks (limestone, dolostone, chert, siltstone, sandstone and wacke). Archean indicator lithologies are ultramafic rocks that occur to the northeast of the Hemlo area (west of White Lake in Fig. 5*b*) and to the north and east of the study area near Manitouwadge, Ontario.

Lower lodgment till pebble assemblages are dominated by distal clasts and contain peridotite at site 5, indicating glacial transport from the northeast. Pebble assemblages suggest that ice movement was across lithologic contacts rather than along them. For example, at site 7 (situated on metavolcanic bedrock) the lower lodgment stones are mainly distal and granitoid, with metavolcanic stones in much lesser proportion but still greater than metasedimentary clasts, indicating debris transport from the north, northeast, or east. Westward or southward provenance would have resulted in much more metasedimentary and less granitoid clasts at site 7. Similar arguments apply to sites 2 and 5 where granitoid clasts are much less abundant and metasediments are in low proportion.

Pebble assemblages in the meltout till are also commonly dominated by distal clasts and contain peridotite at sites 2, 3, and 6 (Fig. 5*b*). Meltout till contains a wider range of stones of local to distal provenance than does the lower lodgment. The Archean clasts were probably derived from upshearing of basal debris when the glacier was still active prior to meltout deposition. Site 4 exemplifies this and is dominated by local metasedimentary rocks (on which it rests), indicating intense erosion of that bedrock prior to meltout deposition. This may also be explained by local glacial entrainment and the meltout of lodged slabs of basal ice at site 4, as mentioned earlier. The clast proportions in this unit also suggest that glacier advance

FIG. 5. Summary of glacial movement directional data: (*a*) kineto-stratigraphic diagram of ice advance directions and (*b*) stone provenance diagram relating stratigraphically arranged pie charts to bedrock lithologies. Lined (distal) pattern in pies includes Paleozoic rocks from the James Bay Lowlands and dark Proterozoic wackes from eastern Hudson Bay (Fig. 1 inset; Shilts 1980). Bedrock map is simplified from Muir (1982*a*, 1982*b*) and Siragusa (1984*a*, 1984*b*, 1985*a*, 1985*b*).


2
SB 6,7a
LL 6,7a(b)
4
7b
SB 5,6,7a
5,6,7a
5
UL 2,7a(b)
SB no data
LL 1
6,7a
6,7a(b)
6,7b
1
UL 2,6,7b(a)
SB 6,7a
3
UL 1,2,5
SB 6,7a
6
UL 2,3,6,7a
SB no data
7
SP ? 7c
SB 6,7c
LL 1,3,4,6,7a
HWY 614
HWY 17
Tek-Corona mine
a
5km
net glacier advance direction; north at top of box
kettle
esker
striae and (or) grooves on bedrock
druminoid ridge
*
SP supraglacial meltout till
UL upper lodgment till
SB subglacial meltout till
LL lower lodgment till
*data from Geddes and Bajc (1985a,b)
Glaciotectonic criteria:
1 extension fractures (e.g. Fig. 3b)
2 shear planes (e.g. Fig. 3f)
3 till wedge (e.g. Fig. 3g)
4 dislodged blocks of bedrock and sediment infillings (3a)
5 displaced fractured boulders in till (e.g. Fig. 3e)
6 striae on top surfaces of stones in till (Fig. 2)
7 stone long axis fabric (Fig. 2)
a: fabric parallel to glacial advance direction
b: fabric transverse to glacial advance direction
c: indeterminate
( ) minor component
Bedrock lithologies:
granitoid
metavolcanic
metasedimentary
Archean
mafic to ultramafic: diabase dyke rock
distal clastic, carbonate, and chert sedimentary rocks
b
SB
LL
2
SB
4
UL
SB
LL
5
UL
SB
1
UL
SB
3
UL
SB
6
SP
SB
LL
7
White Lake
Hemlo mines
5 km

was across lithologic contacts. By way of example, and to compare with the lower lodgment till in the same section, at site 7 Archean clasts have diluted the distal content in the meltout till but local, angular, metavolcanic stones still dominate over metasedimentary clasts. This indicates that glacial debris transport was from an area ranging from the north to the east, as argued above.

The upper lodgment till is also dominated by distal clasts and contains peridotite at site 6 (Fig. 5*b*), indicating that ice advance was from the northeast. As with the lower lodgment till, clast assemblages suggest that ice movement was across lithologic contacts. Finally, at site 7 the supraglacial till is dominated by local, angular, granitic and metavolcanic clasts (Fig. 5*b*). This implies that erosion of the bedrock ridge to the northeast of site 7, and upshearing of local basal debris, occurred when the glacier was active prior to final supraglacial meltout deposition. Glacial debris transport must have been from the northeast since metasedimentary clasts are almost lacking in the till.

Heavy minerals (0.125–0.250 mm fraction) from till matrices were also examined in 21 epoxy-mounted grain mounts (ground to optical thickness) under transmitted polarized light. The size chosen is the most representative of silicate particles formed by glacial comminution far from their source (Dreimanis and Vagners 1971; Gwyn and Dreimanis 1979; Haldorsen 1981). Horneblende, epidote, garnet, opaques, and tourmaline are the most abundant heavy minerals but each occurs in multiple bedrock types in the study area (Muir 1982*b*; Milne 1968), rendering provenance interpretations extremely difficult. Glacial reworking and mixing of mineral grains could also have obscured distinguishing signatures of source areas. Tremolite occurs in most samples and may be derived mainly from ultramafic rocks to the northeast of the Hemlo area (Muir 1982*b*; Milne 1968). If this is the case, it could serve as an indicator, as do peridotite clasts. Light minerals in 12 mounts comprise mainly quartz, plagioclase, and microcline, which occur in all granitoid rocks underlying the area (Muir 1982*b*; Milne 1968), rendering them useless for provenance interpretations. Opaque minerals were studied in polished grain mounts under reflected light and include pyrite and magnetite commonly altered to hematite, minor chalcopyrite cores within pyrite, and rare traces of pyrrhotite. These metallic minerals are typical of the type of crystalline terrain that underlies the study area and are also useless as glacial transport indicators in this case.

Depositional model

Both ice movement indicators and stone provenance support south–southwest glacial advance of the Laurentide ice sheet in the Hemlo area, as determined by Geddes and Bajc (1985*a*, 1985*b*; Fig. 5*a*). These data indicate that the glacier overrode uplands to the northeast of the area that must have influenced deposition of the tills examined in this study. In fact, Geddes and Kristjansson (1986) have observed that the mainly distally derived carbonate tills consistently occur downglacier of uplands located about 20 km upglacier from the Hemlo area. It is proposed below that the carbonate tills resulted from the deposition of englacial debris (Geddes 1984*b*) that was in part carried to the basal zone in the lee sides of uplands as the glacier temporarily experienced extending flow and, later, stagnation.

Lee-side deposition and extending glacial flow have been described for bedrock obstructions by Boulton (1971, 1982), Hillefors (1973), Dreimanis (1976, 1983), Haldorsen (1982), and Dreimanis and Lundqvist (1984) but on a scale of metres. Gillberg (1965), in Sweden, reported on till deposition in the lee sides of bedrock plateaus up to 50 km across and hundreds of metres high. Likewise, Shilts (1973) presented an example from southeastern Quebec with bedrock plateaus 20 km wide and 300 m high. Gillberg's situation may be more similar to that near Hemlo where one of the prominent upland plateaus (west of White Lake) is about 15 km wide and 200 m high (Fig. 1). An hypothesis of ice behaviour and till deposition (as influenced by an upland) follows below, as depicted in Fig. 6, based in part on Gillberg's ideas.

Glacial ice advancing from the north–northeast met the stoss side of the upland and experienced local compressive flow, which was diverted around it while eroding the local bedrock and depositing Geddes' (1984*a*, 1984*c*; Geddes and Bajc 1985*a*, 1985*b*; Geddes *et al.* 1985; Geddes and Kristjansson 1986) subglacial noncarbonate till (Fig. 6*a*). The englacial zone overrode the basal zone and continued to advance over the plateau while downshearing (general meaning of downward transport with or without displacement along slip lines of maximum shear stress in Nye (1952)) its debris during extending flow on the lee side (Fig. 6*b*). Such upshearing of englacial ice over basal ice, and subsequent extending flow, has also been postulated by Shaw (1979) for the formation of Rogen moraines in Sweden. In the Hemlo area, downshearing resulted in lodgment deposition of distally derived englacial debris on the subglacial noncarbonate till. Penecontemporaneously, the stoss side of the upland was eroded by the overriding englacial zone, which upsheared some local debris higher into the ice (Fig. 6*b*). This shear zone may have been analogous to a standing wave in a stream, but with ice moving through it.

After the glacier reached its maximum extent it probably ceased internal flowage (even stagnation) in the Hemlo area whereupon much of the englacial debris was laid down mainly by subglacial meltout (Fig. 6*c*). This mode of deposition is corroborated by the various late-glacial ice disintegration features in the area (Fig. 5*a*). However, subglacial stream and debris flow activity also occurred, as is evidenced by the lenses of gravel and massive silty diamicton within the meltout unit (Fig. 2).

The upper carbonate till probably represents a later reactivation of the glacier during general downwasting, and further deposition of englacial debris as lodgment till (Fig. 6*b*). This event may correlate with the Cochrane readvance of Boissonneau (1966) and Shilts (1980). The fact that the upper lodgment till is richest in distal clasts (Fig. 4*c*) suggests that its particles were transported higher within the englacial zone than those of the lower lodgment till, and that it was deposited after the lower lodgment till. During final ice disintegration the upsheared, angular, supraglacial debris was lowered to the surface of the underlying subglacial meltout till by supraglacial meltout (Fig. 6*d*).

According to the model this unusual shield till sequence could be expected in the lee sides of upland plateaus north of central Lake Superior and perhaps in other shield areas with similar topography that occur downglacier of the James Bay Lowlands. If not for the uplands, most englacially transported Paleozoic and Proterozoic debris would probably have been carried and dispersed into the U.S.A. and calcareous lodgment till would not have formed in the Hemlo area. In order to transport such abundant distal glacial debris to such areas, ice streaming or glacial surging was likely involved.

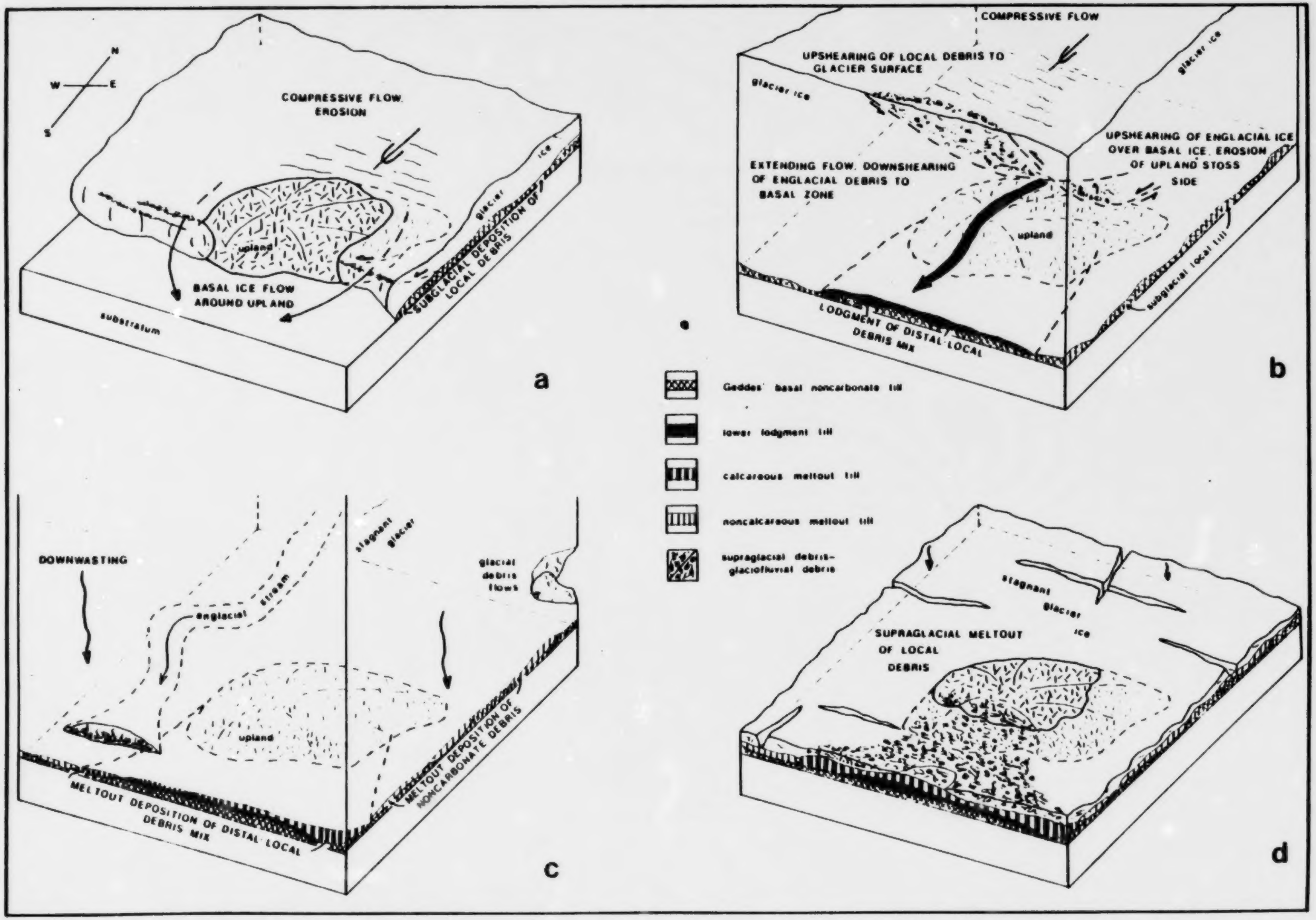

N
W
E
S
COMPRESSIVE FLOW, EROSION
upland
BASAL ICE FLOW AROUND UPLAND
substratum
glacier ice
SUBGLACIAL DEPOSITION OF LOCAL DEBRIS
a
COMPRESSIVE FLOW
UPSHEARING OF LOCAL DEBRIS TO GLACIER SURFACE
glacier ice
glacier ice
EXTENDING FLOW, DOWNSHEARING OF ENGLACIAL DEBRIS TO BASAL ZONE
UPSHEARING OF ENGLACIAL ICE OVER BASAL ICE, EROSION OF UPLAND STOSS SIDE
upland
subglacial local till
LODGMENT OF DISTAL-LOCAL DEBRIS MIX
b
Geddes' basal noncarbonate till
lower lodgment till
calcareous meltout till
noncalcareous meltout till
supraglacial debris-glaciofluvial debris
DOWNWASTING
englacial stream
stagnant glacier
glacial debris flows
upland
MELTOUT DEPOSITION OF DISTAL-LOCAL DEBRIS MIX
MELTOUT DEPOSITION OF NONCARBONATE DEBRIS
c
stagnant glacier ice
SUPRAGLACIAL MELTOUT OF LOCAL DEBRIS
d

FIG. 6. Depositional model: (*a*) early advance stage as the glacier encounters the upland while depositing basal noncarbonate till; (*b*) upshearing of englacial ice over slowed basal ice on the stoss side of the upland and subsequent downshearing on the lee side to form calcareous lodgment till; (*c*) downwasting and subglacial meltout till deposition upon cessation of internal glacial flow; and (*d*) final stage of glacial stagnation and supraglacial meltout till deposition.

The entire till sequence can be explained with one glacial advance during the Late Wisconsinan Substage. This is supported by the lack of paleosols, weathering zones, and rinds on clasts (although rotted granitoid clasts are common at some sites), or organic layers within the drift sequence which might suggest interstadial intervals. Whether the tills were deposited entirely during general deglaciation of the area, or in part by ice advance during the Late Wisconsinan maximum, is very difficult to discern.

Conclusions

Five tills occur in the Hemlo area, three of which were distally derived from at least 150 km upglacier in the James Bay Lowlands. Ice movement indicators and pebble provenance demonstrate that ice advance was south–southwest over uplands about 20 km upglacier from the immediate Hemlo area, across bedrock lithologic contacts. The deposition of all five tills can be explained by a single glacial advance. Penecontemporaneously compressive flow on the stoss sides of uplands upsheared local basal debris high into the ice, while englacial ice overrode the uplands and downsheared englacial debris to deposit lodgment till on their lee sides. Eventually, internal ice flow ceased and glacier downwasting formed subglacial, then supraglacial, meltout tills, with an intervening glacial reactivation.

Therefore, on a practical note, drift prospecting would be hindered by the presence of the carbonate tills because they are mainly distally derived and any ore dispersal trains in them would be too diffuse to trace back to their distant sources (Geddes 1984*a*, 1984*b*, 1984*c*; Kristjansson 1984; Hicock 1986; Geddes and Kristjansson 1986; Karrow and Geddes 1987). The supraglacial till comprises local materials, is richest in metals (including gold), and would be most likely to contain well-defined dispersal trains (Hicock 1986). Geddes' local noncarbonate till would also be a candidate for applying drift prospecting techniques.

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Appendix 3:

Anomalous carbonate till in the Hemlo and Geraldton areas, Ontario: origin and applications. preprint by S.R. Hicock in press with Geoscience Research Grant Program Summary of Research 1986-1987

GRANT 266 ANOMALOUS CARBONATE TILL, HEMLO AND GERALDTON AREAS, ONTARIO: ORIGIN AND APPLICATIONS.

Stephen R. Hicock,
Department of Geology, University of Western Ontario, London

ABSTRACT

Calcareous Shield tills were examined to determine how they were transported and deposited, and how they could affect gold exploration, aggregate quality, and acid rain susceptiblity.

Two highly calcareous tills deposited by lodgment and subglacial meltout are underlain by a local weakly calcareous till and overlain by a weakly calcareous supraglacial meltout till. The entire till sequence can be explained by a single rapid glacial advance over uplands involving simultaneous stoss side upshearing of local rocks and lee side downward transport of distal debris, followed by stagnation. Rapid flow involved ice streaming and/or surging within the Superior glacial lobe and may also explain other carbonate drift belts on the Shield.

Supraglacial till comprises coarse local Precambrian materials and is richest in metals. Carbonate tills comprise finer, dominantly distal materials, with less metals. The supraglacial and local gritty sand tills are most likely to contain well-defined ore dispersal trains that may be traced upglacier to source (probably within 30km). The carbonate tills are too far-travelled to contain distinct and traceable

trains; however, they should make excellent buffers against acid precipitation, and dam cores for acidic mine tailings ponds. Little chert occurs in the tills and aggregate quality should be generally high.

INTRODUCTION:

The normal recommendation in drift prospecting programs is to sample lodgment till, as opposed to other genetic types, because it is dominated by local clasts and should reflect nearby sources of till materials (Goldthwait, 1971; Shilts, 1975, 1984). However, the first phase of this project (Hemlo area) clearly demonstrated that lodgment tills in calcareous drift are a hindrance to mineral exploration because they contain abundant distally derived materials that cannot be easily traced upglacier to source (Hicock 1986 and in press); a conclusion also reached by Geddes and Kristjansson (1986) and Karrow and Geddes (1987). In order to test this hypothesis and assess the regional implications of calcareous drift on gold exploration, the Geraldton area was also investigated during the second phase of the project. As with the Hemlo area, till genesis has important implications for the usefulness of drift prospecting between Geraldton and Beardmore in in locating other gold sources.

This project was initiated in order to assess: 1) the influence of carbonate till on mineral exploration on the

Canadian Shield using drift prospecting; 2) its response to acid precipitation; and 3) to determine till genesis and propose a depositional model for the calcareous drift. These objectives are accomplished in the Geraldton area by analyzing the till character and stratigraphy in order to interpret its mode of formation, occurrence, and provenance.

Field work for phase 2, during three weeks in July, 1986, concentrated on eleven sites (Fig. 1; mainly roadcuts) which were re-exposed with shovels then studied in detail for stratigraphic and structural relations of sediment units. In the laboratory granulometric analyses were performed by the hydrometer-sieve method of the American Society for Testing and Materials (1972), using 0.002 and 0.063 mm as the clay-silt and silt-sand boundaries, respectively. Carbonate analyses were done after the method of Dreimanis (1962) and geochemical analyses were completed by Barringer Magenta Ltd. of Toronto, using atomic absorption techniques on total digests of the -0.002 mm fraction of till matrices.

Till criteria and terminology used in this paper follow the system of the International Quaternary Association's Commission on Lithology and Genesis of Glacial Deposits as summarized by Dreimanis (1982).

PHYSICAL SETTING AND PREVIOUS WORK:

The Geraldton area abounds with glacially-aligned lakes and occupies a broad drumlinized trough with up to 100 m relief that is flanked by distinct uplands to the west, south, and east, as well as a subtle upland north of Geraldton (Fig. 1). The area is underlain by a structurally-complex sequence of Precambrian lithologies including: metavolcanic (mainly greenstone), metasedimentary (including iron formation), and granitoid plutonic and gneissic rocks (Pye et al. 1966; Stott 1984a,b). Diabase dykes have intruded other lithologies and minor patches of ultramafic rocks (mainly peridotite) occur on the bedrock surface.

Recent Quaternary studies north of Lake Superior have concentrated on surficial mapping and glacial lake studies (Farrand 1962; Zoltai 1965a,b,1967; Boissonneau 1966); Zoltai and Boissonneau recognized the carbonate-rich till, as did Sado (1975). Coker and Shilts (1979) generally described the till in a lake geochemistry study, and Fortescue and Geddes (1983), Geddes (1984), Kristjansson (1984, 1986), Geddes and Bajc (1985a,b), Geddes et al. (1985), Woods (1985), Geddes and Kristjansson (1986), Geddes (1986), White (1986), Hicock (1986, in press), and Kristjansson et al. (in press) have described it in more detailed mapping and case studies. Gartner (1979a,b, 1980) and Cooper (1981) provided engineering and terrain studies of the Geraldton area and Karrow and Geddes (1987) summarized the implications of carbonate drift on radiocarbon dating, fossil shell preservation, acid precipitation buffering, and drift prospecting on the Canadian Shield.

TILL STRATIGRAPHY AND GENESIS:

Four tills are recognized in the Geraldton area; two are highly calcareous and are sandwiched between tills with low carbonate content. The oldest is a locally-derived gritty, silty sand till observed by Kristjansson (1984, 1986); it was not encountered in the sections studied by the author.

Lodgment Till

The overlying unit occurs in seven sections and comprises dark grey, compacted, calcareous diamicton. It is fissile, stony, and contains striated, faceted, and bullet-nosed stones, as well as clasts of sand at site 11. Till matrix (-2.00 mm) comprises about 35% sand, 55% silt, 10% clay and 30-40% total carbonates (calcite and dolomite; Table 1). At sites 6 and 10 its upper portion was remobilized to produce a noncompacted massive diamicton.

Stones are generally subrounded to subangular and dominated by Paleozoic lithologies, indicating distal glacial transport. Parallel and transverse alignment of stones in the till, extension fractures, and shear planes within the unit, as well as displaced bedrock blocks in contact with the till, are consistently oriented with striae on the top surfaces of stones.

These characteristics indicate that this compact diamicton was deposited subglacially by lodgment (sensu Dreimanis 1976,1982; Shaw 1985).

Meltout till

The compact calcareous till is overlain by a light grey, noncompacted, coarser-textured diamicton. This calcareous till was observed at five sites and commonly appeared massive although at some sites it contains interlayered and lenticular silt, sand, gravel, and diamictic strata. Bedding in places is truncated by dropstones or draped over them. Striated and faceted stones, as well as clasts of sorted sediment and compact till, are abundant. Till matrices contain 60-70% sand, 20-30% silt, under 5% clay, and 25-35% carbonate (Table 1). Stones are generally subrounded and distal clasts dominate the pebble assemblages. Alignment of stones is commonly parallel to striae on the top surfaces of stones within the till. At some sites the unit extends to the ground surface where it has been heavily oxidized and leached of carbonate by soil development (Table 1, sites 2,10).

These data indicate that this unit was deposited subglacially, mainly by meltout (sensu Dreimanis 1976,1982;

Shaw 1982,1983,1985) but with subglacial stream and subglacial debris flow forming some of the gravelly and diamictic strata.

Supraglacial Drift (till and boulder mantles)

At site 3 noncompacted, weakly calcareous, coarse-textured diamicton (Table 1) dominated by subangular Precambrian clasts (many of them rotten) comprises the section, which contains a large angular block of highly calcareous till. The section occurs in a mound mantled by large subangular granitoid boulders. Other boulder-mantled mounds occur near the site and Precambrian blocks commonly mantle the ground surface at other sites. Stone alignment at site 3 is bimodal and unrelated to ice movement.

This material was most likely deposited by supraglacial meltout, commonly as kames and Precambrian boulder mantles. Younger glaciofluvial and glaciolacustrine sediments were studied by Kristjansson et al. (in press).

GLACIER MOVEMENT AND CLASTIC DISPERSAL:

An accurate knowledge of glacier movement directions in the Geraldton area is essential for developing a strategy for mineral exploration by drift prospecting, as well as constructing a depositional model for the tills and determining their source areas. Zoltai (1967), Sado (1975), and Kristjansson et al. (in press) determined that general ice advance was towards the southwest.

Lodgment Till

All fabric orientations (pebble long axes) in the lodgment till display both parallel and transverse clast alignment indicating that glacier advance was towards the southwest, which agrees with the dips of extension fractures, shear planes, and displaced bedrock, as well as striae on stones within the till. Distal lithologies dominate the stones (Table 1) but local rocks have been incorporated, including serpentinized peridotite originating just southward of Geraldton.

Meltout Till

Fabric orientations in the meltout till suggest that glacial advance was generally to the southwest, which is supported by striae on stones in the unit. Distal clasts are commonly the most abundant but stones of local to intermediate provenance (including peridotite) were also upsheared into the ice when it was actively advancing prior to meltout deposition.

Supraglacial Drift

The bimodal fabric in supraglacial till at site 3 is unrelated to ice movement but the drift is clearly dominated by angular local clasts, including peridotite derived from the northeast.

Summary

The glaciotectonic and fabric data agree with the ice movement data of Zoltai (1967), Sado (1975), and Kristjansson et al. (in press) and clearly indicate southwestward advance. Paleozoic, peridotite, and dark wacke clasts confirm this since they originated from bedrock sources to the northeast. The Paleozoic pebbles were derived from the James Bay Lowland, at least 120 km distant, and the wackes from the east side of Hudson Bay (Shilts 1980,1982,1984). Pebble assemblages indicate that ice advanced southwestward across lithologic contacts rather than parallel to them.

GEOCHEMICAL GLACIAL DISPERSAL:

Atomic absorption analyses of the -0.002mm fraction in till matrices for eight metals and three semimetals are presented in Table 2. This size fraction was chosen because it most accurately reflects pre-weathering proportions of metals in the till matrix (Shilts 1975,1984).

The supraglacial meltout till is clearly richest in metals, especially gold, whereas the highly calcareous tills contain lesser amounts. Meltout till is generally richer in metals than the lodgment facies but has lesser matrix carbonate. The relationship between metal content and matrix carbonate is demonstrated in Fig. 2 for four representative metals; in general, as matrix carbonate increases, metal content decreases. This trend reflects relative dilution of metals of local to intermediate provenance by distal carbonate matrix during glacial transport and deposition. Supraglacial till has low carbonate matrix and better reflects the local bedrock geochemistry.

MODE OF GLACIAL TRANSPORT AND TILL DEPOSITION:

The entire till sequence in the Geraldton area can be explained by one glacial advance over uplands to the northeast (Fig. 1). The carbonate-rich tills probably resulted from rapid ice stream erosion of carbonate bedrock in the James Bay Lowland and subsequent deposition in the lee sides of uplands where englacial debris was transported downwards to the basal zone as the glacier experienced enhanced extending flow, followed by stagnation. The depositional model for phase I of this project (Hemlo) also applies here and was presented by Hicock (1986; in press). Extending flow was probably also part of the rapid glacial movement (surging and/or ice streaming) in prominent lobes along the southern margin of the Late Wisconsinan Laurentide Ice Sheet (Wright 1973; Boulton and Jones 1979; Boulton et al. 1985; Clayton et al. 1985; Beget 1986; Hicock et al. in press), in this case the Superior lobe. In this way large quantities of Paleozoic carbonate debris were rapidly transported great distances over the Canadian Shield and deposited on it as belts of thick carbonate till (cf. Karrow and Geddes 1987; Hicock et al. in press).

In the Geraldton area glacier ice streaming from the northeast (probably out of the James Bay Lowland via the Albany-Drowning corridor and Nakina) met the stoss side of the granitoid upland belt north of Geraldton. Local compressive flow was induced and diverted around the uplands (as well as inducing upshearing of glacial debris), eroding the local bedrock and depositing Kristjansson's (1984, 1986) local gritty sand till. The englacial zone overrode the retarded basal ice and continued the stoss-side upshearing of local debris to or near the glacier surface. It then spilled over the bedrock step and into a structural trough southwest of Wildgoose Lake while its debris was transported downwards with extending flow. This resulted in lodgment of englacial debris on top of the gritty sand till, in the lee side of the upland.

After the glacier reached its maximum extent it probably stagnated in the Geraldton area where much glacial debris was deposited by subglacial meltout. A late rejuvenation of the glacier occurred during general downwasting which carved drumlins into the carbonate tills and probably correlates with the deposition of an upper lodgment till in the Hemlo area (Hicock 1986; in press).

Finally, upland stoss-side debris that was upsheared to or near the glacier surface was passively lowered onto the underlying calcareous meltout and lodgment tills by supraglacial meltout, in some places as kames. This is supported by the various late glacial ice retreat and disintegration features in the area (Zoltai 1967; Sado 1975; Kristjansson 1986; Kristjansson et al. in press).

ECONOMIC AND ENVIRONMENTAL ASPECTS:

As with the first phase of the project (Hicock 1986, in press), these results and interpretations indicate that an understanding of till genesis, stratigraphy, and ice movements are important for mineral exploration strategies and environmental considerations. Some recommendations are presented below for the Geraldton area.

Drift Prospecting

The supraglacial meltout till and the local gritty sand till, in which significant gold was also found (F. Kristjansson, pers. comm., 1987), are best to sample in overburden drilling programs.

They comprise material that has been transported for relatively short distances (mainly derived from uplands less than 30km upglacier; Fig. 1) and are, therefore, most likely to contain well defined dispersal fans of ore anomalies which may be traced back to source (cf. Shilts 1976, 1984). This is exemplified by the relatively high gold value in the supraglacial till, which occurs within an area of gold exploration.

The calcareous tills, however, are a hindrance to drift prospecting (Kristjansson 1986) because they contain mainly distally-derived material (much of it from at least 120km away) which mask dispersed ore of local to intermediate provenance. Any disperal fans within the calcareous tills will probably be too diffuse to recognize (with ore values near background this far downglacier from distal ore sources) or to successfully trace anomalies back to source.

Aggregate Quality

As in the Hemlo area (Hicock 1986), chert is a minor component in the drift studied around Geraldton and should cause no problems with gravel use. In several sections rotted clasts of granitoid and metasedimentary rocks occurred. At site 3 the supraglacial till was dominated by completely decomposed purple metasedimentary clasts and the unit will present a problem for aggregate use if this is found to be a trend in it.

Acid Rain

The calcareous tills should be excellent buffers. They are as calcareous as those overlying carbonate bedrock in southern Ontario where till matrix carbonate would attain a maximum.

Map unit 3 of Kristjansson et al. (in press) is the least susceptible to acid rain. Thus a map of acid rain susceptibility could be constructed based on the matrix carbonate of the various sediment units in the area, such as that attempted by Woods (1985, p.45) for the Hemlo area.

Lakes within areas of calcareous glacial drift are more alkaline than those without and also serve as buffers (ibid.; Coker and Shilts 1979).

Tailings Dam Cores

The calcareous lodgment till would probably make good low-permeablility cores with high capacity for buffering acidic mine tailings, as it does in the Hemlo area (Hicock 1986).

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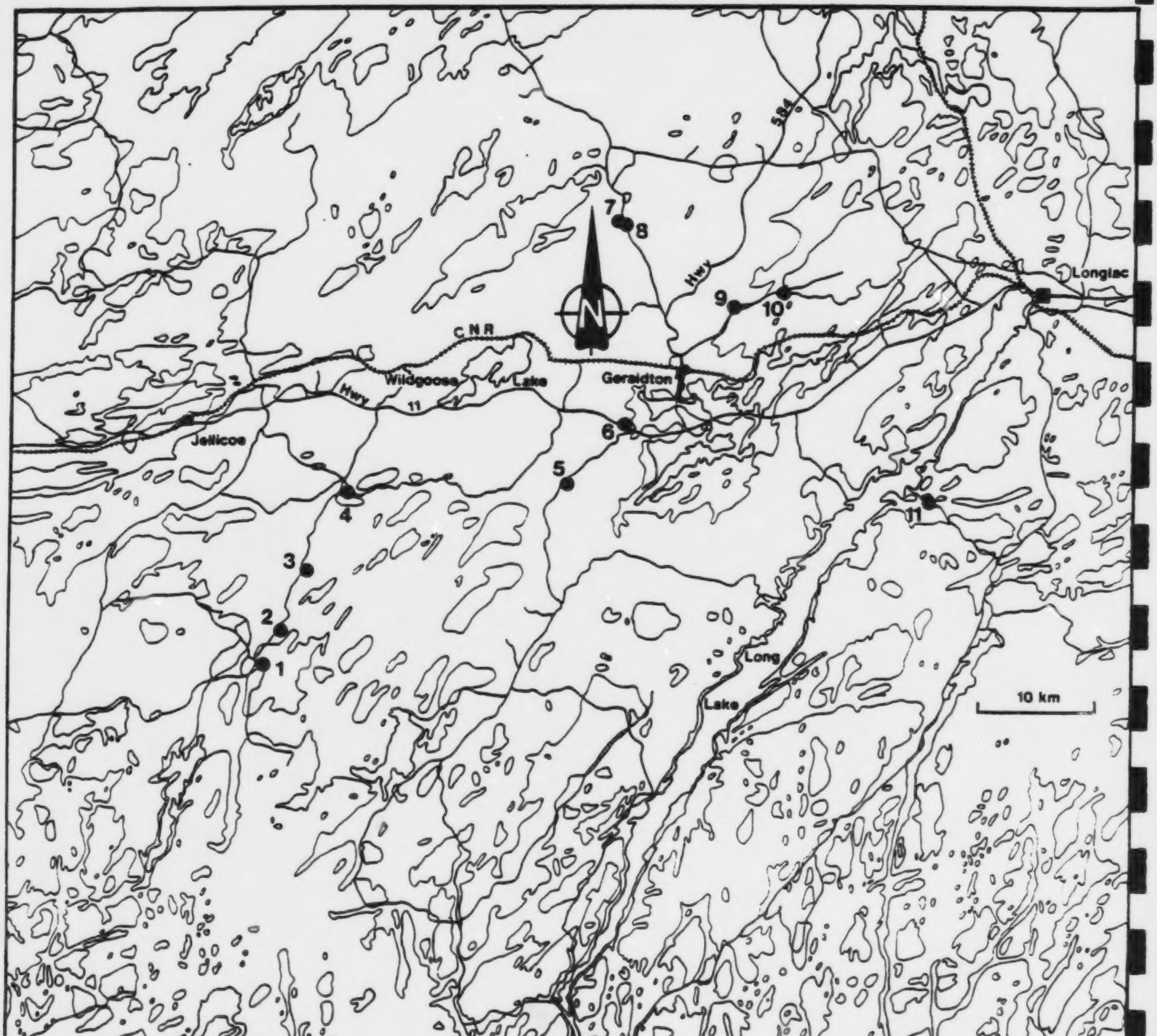
Figure Captions:

Grant 266 Fig. 1: Topographic map of the study area with site localities. Contour interval is 60 m.

Grant 266 Fig. 2: Geochemical comparison of representative metals in Geraldton till matrices (-0.002mm fraction), excluding leached samples from sites 2 and 10, with percent matrix carbonate (-0.063mm fraction).



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Lake
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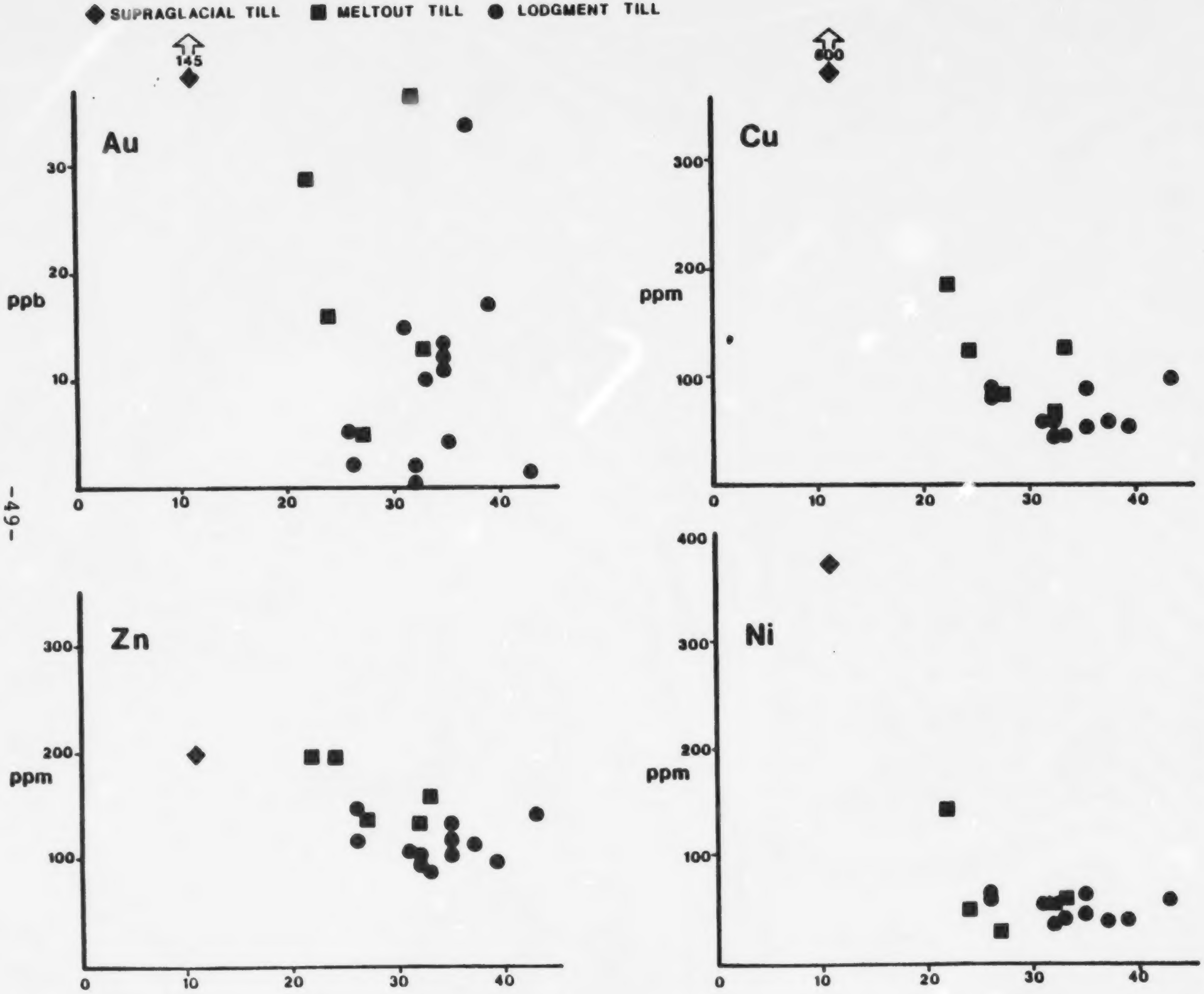
Fig. 2 [illegible]



◆ SUPRAGLACIAL TILL
■ MELTOUT TILL
● LODGMENT TILL
145
Au
ppb
30
20
10
0
10
20
30
40
600
Cu
ppm
300
200
100
0
10
20
30
40
Zn
ppm
300
200
100
0
10
20
30
40
Ni
ppm
400
300
200
100
0
10
20
30
40

Grant 266 Table 1: Geraldton Till Matrix and Pebble Data

Till	Site	Matrix Grain Size			Matrix Carbonate		Pebble data	
	on	(-2.0mm fraction)			(-0.063mm fraction)		(1-10cm fraction)	
unit	Fig.1	%sand	%silt	%clay	%carb	cal/dol	roundness	Distal/Prec
supra-glacial	3	62	37	1	11	0.2	sa-sr	0.5
melt-	2 oxidized	61	37	02	0	0	sr-sa	1.0
out	2	62	36	02	22	0.2	sr-sa	1.6
	7 upper	70	28	02	24	0.3	sr-sa	0.9
	7 lower	65	33	02	27	0.5	sa-sr	1.3
	9	74	23	03	33	0.7	sr-sa	1.4
	10 oxidized	63	34	03	0	0	sa-sr	1.6
	10	59	38	03	32	0.5	sr-sa	5.7
lodgment	1	45	48	07	26	0.5	sa-sr	1.2
	4 upper	42	50	08	44	0.9	sr-sa	2.6
	4 lower	38	55	07	31	0.7	sr-sa	3.8
	5	34	59	07	37	0.9	sr-sa	4.6
	6 clasts	23	68	09	39	0.7	sr-sa	4.3
	in meltout	30	53	17	33	0.9	sr-sa	-
	6 remobilized	35	59	06	35	0.6	sr-sa	5.3
	6	31	53	16	32	1.4	sr-sa	1.9
	8	43	48	09	26	0.7	sr-sa	6.1
	10 remobilized	32	62	06	35	0.6	sr-sa	4.9
	11	43	48	09	35	0.9	sr-sa	-
	11	36	56	08	32	0.9	sr-sa	1.2

cal=calcite, dol=dolomite, carb=total calcite and dolomite

Distal=Paleozoic+Proterozoic(wacke) lithologies; Prec=Archean lithologies

sa=subangular, sr=subrounded

Grant 266 Table 2: Geochemical Analyses of Geraldton Till Samples (-0.002mm fraction)

Site	Till facies	Cu ppm	Ni ppm	B ppm	Mn ppm	Zn ppm	Mo ppm	As ppm	Sb ppm	W ppm	Te ppm	Au ppb
1	lodgment	90	65	22	460	120	<1	11.0	.2	6	<.2	5
2	meltout	190	145	35	790	195	<1	7.5	.2	20	<.2	29
2	meltout oxidized	200	500	31	760	140	<1	20.0	.3	12	.2	4
3	supra-glacial	600	375	38	1250	200	<1	23.5	.5	350	.2	145
4	lodgment	100	60	39	560	145	<1	6.0	.2	16	<.2	1
4	lodgment	60	55	35	480	110	<1	5.0	.2	4	<.2	15
5	lodgment	60	40	28	460	115	<1	5.0	.2	6	<.2	34
6	lodgment clast in meltout	55	40	43	520	100	<1	4.5	.2	12	<.2	17
6	lodgment clast in meltout	47	40	31	490	90	<1	4.0	<.2	<4	<.2	10
6	lodgment remobilized	55	45	36	540	105	<1	4.5	.2	4	<.2	12
6	lodgment	45	35	36	475	95	<1	4.0	.2	8	<.2	2
7	meltout	125	50	36	780	195	<1	5.5	.2	8	<.2	16
7	meltout	85	30	31	640	140	<1	3.5	.2	100	<.2	5
8	lodgment	80	60	40	530	150	<1	4.5	<.2	16	<.2	2
9	meltout	130	60	40	640	160	<1	7.5	.2	4	<.2	13
10	meltout	70	55	33	610	135	<1	7.0	.2	4	<.2	37
10	meltout oxidized	80	75	9	300	100	<1	11.0	.2	6	<.2	1
10	lodgment remobilized	90	45	37	520	135	<1	5.5	.2	4	<.2	4
11	lodgment	90	65	28	530	120	<1	26.5	.3	4	<.2	11
11	lodgment	60	55	28	570	105	<1	16.5	.2	4	<.2	<1

Appendix 4:

Calcareous till and Late Wisconsinan ice streaming north of Lake Superior, Ontario. preprint by S.R. Hicock submitted to Geographie physique et Quaternaire.

CALCAREOUS TILL AND LATE WISCONSINAN ICE STREAMING NORTH OF LAKE SUPERIOR, ONTARIO.

Stephen R. Hicock,
Department of Geology, The University of Western
Ontario, London, Ont. N6A 5B7

S.R. Hicock August 1987

ABSTRACT

Belts of thick calcareous till lie on the Canadian Shield whose materials were glacially transported hundreds of kilometres from sources in the James Bay Lowlands and the eastern shore of Hudson Bay. In the Geraldton and Hemlo areas carbonate till packages lie between weakly to noncalcareous tills and can be distinguished by textural, carbonate, and clast compositions. Their occurrence and uniform character over large areas of the Shield attest to rapid movement of distal debris within the southern margin of the Laurentide Ice Sheet. This is consistent with low surface profiles reconstructed for the Superior and Michigan lobes which were likely fed by ice north of Superior and probably affected by ice streaming (as opposed to periodic surging), if Late Wisconsinan Laurentide spreading centres were long-lived.

Stratigraphic, lithologic, and structural studies suggest that till deposition in the Geraldton and Hemlo areas can be explained with one Late Wisconsinan southwestward glacial advance. A broad ice stream probably issued out of James Bay and up the Albany conduit between zones of normal ice velocity within the Laurentide marginal area. It may have split to flow down the Drowning and Kenogami troughs over soft

Paleozoic sedimentary rocks which were readily eroded and upsheared for englacial transport, especially near the Paleozoic-Shield contact. Eventually zones of ice streaming reached the Geraldton and Hemlo areas where Shield uplands induced lee side extending flow, downward transport, and lodgment of calcareous englacial debris on local tills. Following the glacial maximum much of the distal englacial debris was laid down by subglacial meltout. However, a glacial reactivation occurred carving drumlins into the carbonate tills near Geraldton and depositing an upper calcareous lodgment till at Hemlo. Final Laurentide decay resulted in meltout of supraglacial debris that had been upsheared to or near the glacier surface from the stoss sides of the uplands.

INTRODUCTION:

Recent studies suggest that calcareous glacial drift is not uncommon on the Canadian Shield (GEDDES, 1984; GEDDES and BAJC, 1985a, 1985b; GEDDES et al., 1985; GEDDES and KRISTJANSSON, 1986; KRISTJANSSON, 1986; HICOCK, 1986, 1987a, 1987b, 1987c; KARROW and GEDDES, 1987). Two areas containing calcareous lodgment tills, near Hemlo and Geraldton, were recently studied by the author. The occurrence of these lodgment tills raises the question of how their particles could have been glacially transported hundreds of kilometres from their Paleozoic and Proterozoic sources in the James Bay Lowlands and eastern shore of Hudson Bay, respectively (Fig. 1 inset). The purpose of this paper is to 1) explain the entrainment, transport, and deposition of such abundant distal materials found in the tills, and 2) to suggest how this relates to flow dynamics within the southern margin of the Laurentide ice sheet. Calcareous till in the gold-rich Hemlo area was explained in HICOCK (1987b) where uplands affected glacier flow dynamics. This paper examines another Shield area of carbonate till in the gold-bearing Geraldton area and relates the two areas in order to explain Late Wisconsinan Laurentide flow behaviour north of Lake Superior.

Field work in the Geraldton area was done on old road cuts and an abandonned gravel pit in July, 1986. Eleven exposures were re-excavated with hand shovels, carefully cleaned with knives, and studied in detail for stratigraphic and structural relations of sediment units. Samples were collected for grain size, carbonate, pebble lithology, geochemical, and heavy mineral analyses in order to characterize the units and determine their modes of deposition and provenance. Granulometric analyses were performed by the hydrometer-sieve method of the AMERICAN SOCIETY FOR TESTING AND MATERIALS (1972), using 0.002 and 0.063 mm as the clay-silt and silt-sand boundaries, respectively; carbonate analyses after the method of DREIMANIS (1962); and heavy mineral separations using liquid sodium polytungstate (specific gravity 2.90). Computer analyses of pebble long axis orientations (fabrics) were accomplished with the method of MARK (1973, 1974).

Till criteria and terminology used in this paper follow the system of the International Union for Quaternary Research's Commission on Lithology and Genesis of Glacial Deposits as summarized by DREIMANIS (1982).

PHYSICAL SETTING AND PREVIOUS WORK:

The Geraldton area abounds with glacially-aligned lakes and occupies a broad drumlinized trough with up to 100 m surface relief (Fig. 1). It is filled with calcareous drift up to 160 m thick (F.J. KRISTJANSSON, pers. comm., 1987) and flanked by distinct uplands to the west, south, and east, as well as a subtle upland north of Geraldton. The area is underlain by a structurally-complex sequence of Archean lithologies including: metavolcanic (mainly flows, amphibolites, and pyroclastic rocks), metasedimentary (clastic and chemical rocks including iron formation), and granitoid plutonic (mainly tonalite to granodiorite) and gneissic rocks (presented later in Fig. 5b). Diabase dykes have intruded other lithologies ubiquitously and scattered patches of mafic to ultramafic rocks (gabbro, peridotite, serpentinite) can be found.

Recent Quaternary studies north of Lake Superior have concentrated on surficial mapping and glacial lake studies (FARRAND, 1962; ZOLTAI, 1965a, 1965b, 1967; BOISSONNEAU, 1966); Zoltai and Boissonneau recognized the carbonate-rich till, as did SADO (1975). COKER and SHILTS (1979) generally described the till in a lake geochemistry study, and FORTESCUE and GEDDES (1983), GEDDES (1984, 1986), KRISTJANSSON (1984, 1986), GEDDES and BAJC (1985a, 1985b), GEDDES et al. (1985), WOODS (1985), GEDDES and KRISTJANSSON (1986), WHITE (1986), HICOCK (1986, 1987b, 1987c), and KRISTJANSSON et al. (in press) have described it in more detailed mapping and case studies. GARTNER (1979a, 1979b, 1980) and COOPER (1983) provided engineering and terrain studies of the Geraldton area and KARROW and GEDDES (1987) summarized the implications of carbonate drift on radiocarbon dating, fossil shell preservation, acid precipitation buffering, and drift prospecting on the Canadian Shield. Finally, SHILTS (1980, 1982, 1984, 1985), DYKE et al. (1982), FISHER et al. (1985), BOULTON et al. (1985), VEILLETTE (1986), DYKE and PREST (1987), and DYKE et al. (in press) documented and modelled regional glacier flow patterns beneath the central part of the Laurentide Ice Sheet.

Pleistocene sediments in the region appear to have been deposited during the Late Wisconsinan Substage. The oldest radiocarbon date is 9380 + 150 years BP (GSC-287; ZOLTAI 1965a) from wood in lateglacial lake deposits.

CHARACTER AND STRATIGRAPHY OF GERALDTON TILLS:

Four tills are recognized in the Geraldton area. Two are highly calcareous and are sandwiched between tills with lower carbonate content. The oldest sediment encountered in mine excavations and drillholes is a locally-derived gritty sand till observed by KRISTJANSSON (1984, 1986); it was not encountered in the sections studied by the author.

The overlying unit occurs in seven of the eleven sections studied, which are presented diagrammatically in Fig. 2 and pictorally in Fig. 3. It comprises dark grey, compacted, calcareous diamicton which is at least 2.5 m thick at site 4. The diamicton is fissile, stony, and contains striated, faceted, and bullet-nosed stones, as well as rare pockets of sand at site 11. Diamicton matrix (-2.00 mm) comprises about 35% sand, 55% silt, 10% clay (Fig. 4a), and 30-40% total carbonates (calcite and dolomite; Fig. 4b). Stones are generally subrounded to subangular and dominated by Paleozoic and Proterozoic lithologies, indicating distal glacial transport (Fig. 4c). Parallel and transverse alignment of stones in the diamicton, as well as displaced striated bedrock blocks in contact with the till west of site 6 (Fig. 3a), extension fractures (Fig. 3b), striated, stoss and lee boulders in pavements at site 4 (Fig. 3c), and a sand-filled shear plane at site 5, are consistently oriented with striae on the stones (Fig. 2). The above characteristics indicate that this compact diamicton was deposited subglacially under moving ice by lodgment as defined by DREIMANIS (1976, 1982) and SHAW (1985). The diamicton is therefore called lodgment till. At sites 6 and 10 crumbly, dark grey, massive sandy silt diamicton directly overlies the lodgment unit (Fig. 3d) and is interpreted as having flowed from it. Grain size, carbonate, and stone contents are indistinguishable between the two diamictons.

At site 6 lodgment till is underlain by bedded and faulted sand in the lee side of a bedrock knob. The equal area, lower hemisphere, stereographic projection of bedding and fault planes, as well as axial planes of mud flow lobes within the sand (Fig. 2), indicate that the structures are unrelated to ice movement data at or near the site. The sand probably formed as an advance proglacial or subglacial outwash fan in the lee side of the knob which was penecontemporaneously overridden by the glacier. The faults likely reflect dewatering and gravity settling of the sand. Between the sand and till are interbedded current-bedded sand and diamicton layers mm to cm thick. These probably represent proglacial or subglacial debris flows down the sand surface prior to ice grounding and lodgment of the overlying till. In fact the attitude of the sand/diamicton contact is similar to that of the sand bedding (Fig. 2) suggesting flow down the fan. This glacial sequence formed a crag and tail feature near the site which is visible on airphotos and whose long axis is parallels drumlins and bedrock striae in the area.

The compact calcareous till is overlain by a light grey, noncompacted, generally coarser-textured diamicton complex. This calcareous diamicton was found at five sites and is at least 5 m thick at site 7 (Fig. 2). At site 6 where the contact was observed it appeared transitional. At some sites the unit extends to the ground surface where it has been heavily oxidized and leached of carbonate by soil development. This unit is commonly massive but at some sites it contains interlayered and lenticular silt, sand, gravel, and massive silty diamictic strata. Bedding is commonly truncated by dropstones or draped over them (Fig. 3e). Striated and faceted stones, as well as clasts of sorted sediment and compact till, are abundant. The occurrence of delicate sediment clasts, many of them angular (Fig. 3f), precludes basal transport involving subglacial shearing (SHAW, 1982, 1985). Diamicton matrices contain 60-70% sand, 20-30% silt, under 5% clay (Fig. 4a), and 25-35% carbonate (Fig. 4b). Stones are generally subrounded to subangular and the distal content varies in pebble samples but is more similar to the Archean content than in the lodgment till (Fig. 4c). Alignment of stones is generally parallel or transverse to striae on stones within the diamicton (Fig. 2).

The above data indicate that this unit was formed (in the meaning of SHAW, 1982, p.1548) passively under and within inactive ice, mainly by meltout as defined by DREIMANIS (1976, 1982), SHAW (1979, 1982, 1985), and HALDORSEN and SHAW (1982), but with subglacial to englacial streams and debris flows forming some of the sorted and diamictic strata, respectively.

Pressure melting and lodgment probably also participated in the formation of part of the unit, prior to final deposition (in the meaning of SHAW, 1982, p. 1548), since boulder pavements were found within it at site 7 (Figs. 2, 3g). Pavement pebble fabrics and striae on cobbles and boulders are consistently oriented but transverse to cobble and boulder long axes, implying compressive glacier flow at the site and rotation of the larger clasts. The pavements probably formed by lodgment superimposed on successive slabs of stationary debris-rich basal ice that were melting. Thus final deposition of the pavements, and interpavement glacial debris and layering, was by subglacial meltout. Section 7 may represent a transition from lodgment to subglacial meltout processes as internal movement within the basal zone of the glacier sporadically ceased.

At site 3 noncompacted, weakly calcareous, coarse-textured diamicton (Fig. 4a,b) is dominated by subangular Archean clasts (many of them rotted metasediments; Figs. 3h, 4c) and contains a large block of calcareous till (Figs. 2, 3h). The section occurs in a mound mantled by large subangular granitoid boulders. Other boulder-mantled mounds occur near the site and granitoid blocks commonly mantle the ground surface at other sites. Stone alignment at site 3 is bimodal but appears to be mainly a transverse fabric, inferring compressive glacial flow and erosion of granitoid uplands north of Geraldton (Fig. 1).

Some of the mounds are kames and the diamicton and boulder mantles are most likely supraglacial drift formed by the lowering of debris by supraglacial meltout from or near the ice surface. The striated, subrounded distal clasts at site 3 were probably upsheared to or near the supraglacial position of the transporting glacier prior to lowering its debris cover to ground level during deposition of the supraglacial meltout till. Younger glaciofluvial and glaciolacustrine sediments were studied by KRISTJANSSON (1986) and KRISTJANSSON et al. (in press) and are not dealt with here.

In summary, the till units can be differentiated by their matrix textural compositions and generally by their carbonate contents, and clast lithologies (Fig. 4). The lodgment till is characterized by a finer and more calcareous matrix with calcite/dolomite (c/d) ratios commonly between 0.7 and 1, and it generally contains over 70% distal clasts. The subglacial meltout till complex tends to be sandier, less calcareous with c/d ratios commonly less than 0.7, and more equal proportions of distal and Archean stones. At site 3 supraglacial till is coarse like the meltout, but weakly calcareous and comprises mainly subangular Archean clasts.

GLACIER ADVANCE DIRECTION:

An accurate knowledge of glacier movement directions in the area is essential for developing a depositional model for the tills and determining their source areas. A summary of ice advance directions is presented in a kineto-stratigraphic diagram (Fig. 5a), which indicates that ice advance was generally towards the southwest and agrees with ice movement data on the map which was compiled from ZOLTAI (1967), SADO (1975), GARTNER (1979, 1980), and KRISTJANSSON et al. (in press), and is also consistent with the elongation of lakes in Fig. 1. However, ZOLTAI (1967) and KRISTJANSSON (1986) also found an older, southward, striae record on bedrock in the Geraldton area which may be associated with the gritty sand till or an earlier glacial advance whose only remaining evidence is the striae.

In the lodgment till fabric orientations of pebble long (a) axes are generaly well developed, commonly display both parallel and transverse clast alignment (Fig. 2), and indicate that general glacier advance was towards the southwest. At sites 6 and 11 low eigenvalues reflect attempts by the computer to average bimodal fabrics and thus do not accurately represent the degree of fabric development (WOODCOCK, 1977; DOWDESWELL et al., 1985; DOWDESWELL and SHARP, 1986). Sand-filled extension fractures within the unit at site 4 (formed penecontemporaneously with till deposition; Fig. 3b) dip downglacier (BROSTER et al., 1979; HICOCK and DREIMANIS, 1985), a sand-filled shear plane at site 5 rises downglacier (HICOCK and DREIMANIS, 1985), and striated bedrock slabs are slightly displaced downglacier and intervening spaces filled with lodgment till west of site 6, along Highway 11 (Fig. 3a). These data support the southwest trend, as well as striae on the top surfaces of stones within the till and long axes of cobbles and boulders.

At site 6 the pebble fabric is oriented almost north-south (Fig. 2) and probably reflects locally convergent glacier flow into the lee side of the rock knob (the crag of the crag and tail feature). At site 4 a few of the boulder long axes are transverse to the others in the lower pavement which is consistent with the strongly oriented bimodal pebble fabric data. Fabrics of remobilized lodgment till at sites 6 (Fig. 3d) and 10 are interpreted as girdles reflecting flowage of the diamicton from its parent lodgment till. At site 11 the fabric is nearly random and may reflect winter frost activity as the analysis was performed near the ground surface.

Pebble fabrics in the meltout till also display parallel-transverse combinations and suggest that glacier advance was to the southwest, with some local variations. This is supported by striae on stones as well as cobble and boulder long axes in the unit (Fig. 2). At site 7 a westward shift in glacier flow direction between boulder pavements (Fig. 3g) is indicated. Pavement boulder long axes at that site are transverse to boulder striae and bimodal pebble fabrics, which implies compressive glacial flow and supports the argument that the pavements were lodged prior to final deposition by meltout. At site 10 fabrics are interpreted as girdles representing flowage of the silty facies of the meltout unit and winter frost activity where the upper analysis was conducted near the ground surface.

Finally, the pebble fabric in supraglacial meltout till at site 3 appears to be a southward transverse fabric implying compressive glacier flow and upshearing of subangular Archean debris to or near the glacier surface. This would most likely have occurred against the stoss side of granitic uplands north of Geraldton.

TILL PROVENANCE:

Besides the ice movement indicators summarized in Fig. 5a, determination of source areas of the till materials is valuable information for checking advance directions, as well as interpreting modes of glacial transport and deposition. It is obvious that the Paleozoic carbonate clasts and Proterozoic dark wackes must have been distally derived from the James Bay Lowlands and eastern shore of Hudson Bay, respectively, (Fig. 1 inset) and that ice advance was southwestward to Geraldton from those source areas (ZOLTAI, 1967; SADO, 1975; SHILTS, 1980, 1982, 1984, 1985;

KRISTJANSSON, 1984,1986; HICOCK, 1987a, 1987c). In general lodgment till is richest in silt and clay, matrix carbonate, calcite, and distal clasts (Fig. 4) suggesting that soft sedimentary debris, derived from hundreds of kilometres upglacier, was easily comminuted and rapidly transported to the Geraldton area. However, in addition to the obvious distal provenance, a study of the Archean lithologies in the till samples may help to refine the interpretation of ice movements in the Geraldton area and supplement the glaciotectonic data presented above.

Pebble lithologic data for the Geraldton area is presented stratigraphically as pie diagrams in Figure 5b. Stones ranging from 1 to 10 cm diameter were collected and many thin sectioned and identified under transmitted polarized light until sufficient confidence was gained to identify the remainder under a binocular microscope. The clasts were then subdivided into seven categories reflecting the bedrock lithologies around the study area: Archean granitoid (mainly tonalite and granodiorite); metavolcanic (metabasalt, amphibolite, pyroclastics); metasedimentary (intermediate-grade schists, pelites, and iron formation); diabase dyke rock; mafic to ultramafic (gabbro, peridotite, and serpentinite); Paleozoic sedimentary rocks (limestone, dolostone, chert, siltstone, and sandstone); and Proterozoic dark wackes. There are no reliable Archean indicator lithologies. Mafic to ultramafic rocks are most abundant in an east-west belt south of Geraldton, however, other smaller patches occur in the study area, especially near Jellicoe (Fig. 5b). Similarly, iron formation is most common near Geraldton but is also scattered throughout the area in thin ribbons (STOTT, 1984).

Lodgment till pebble assemblages are clearly dominated by distal clasts and imply only minor erosion and entrainment of Archean rocks of local to intermediate provenance. The Archean pebble component suggests that ice movement was across lithologic contacts rather than along them, assuming that some Archean bedrock erosion occurred. For example, at site 1 (situated on granitoid bedrock) Archean stones comprise roughly equal amounts of granitoid, metavolcanic, and metasedimentary clasts, indicating debris transport from the northwest, north, or northeast. Westward provenance would have resulted in much more metasedimentary clasts, and southward or eastward provenance would have yielded more granitoid clasts at site 1. Rapid glacier flow and minor local erosion is implied by the relatively small amount of metasedimentary clasts, which should be higher if active glacial erosion occurred since ice movement data (Figs. 2,5a) indicate that ice traversed some 30 km of metasedimentary terrain before reaching site 1. Alternatively, ice may have been separated from the bedrock by older drift but if it was the local sand till then reworking would have resulted in less matrix carbonate and more local materials, unless ice travel was rapid enough to even preclude significant erosion of underlying drift. Similar arguments apply to sites 5 and 6 where Archean clasts are much less abundant but metavolcanics are in higher proportion than at site 1, and a large belt of metavolcanic bedrock occurs north of Geraldton. Site 8 epitomizes the argument for rapid flow and reduced local erosion prior to lodgment. It lies at the southern edge of a large granitoid complex yet contains few granitoid pebbles and is clearly dominated by distal lithologies (86% in Fig. 5b). However, in support of ice-bedrock interaction downglacier, the fact that the Archean component is so low in till resting on resistant granitoid terrain implies that some erosion of softer metasedimentary and metavolcanic bedrock did occur to the south where the Archean pebble components are higher in lodgment samples. Peridotite at site 4 indicates that ice came from a northward, as opposed to southward, source. Site 11 implies ice advance from the northeast since other directions would have yielded higher amounts of granitoid or metasedimentary stones.

Pebble assemblages in the meltout till are also commonly dominated by distal clasts but contain a wider range of stones of Archean to distal provenance than does the lodgment. The Archean clasts were probably derived from upshearing of basal debris when the glacer was still active prior to meltout deposition. Site 7 exemplifies this and contains abundant subangular granitoid rocks (on which it rests) indicating erosion of a granitoid upland just north of site 7 prior to meltout depostion. This is consistent with local glacial entrainment and the meltout of lodged slabs of basal ice at site 7, as mentioned earlier. Site 6 may also reflect some local upshearing, or perhaps reworking of older drift, as it is almost devoid of granitoid clasts but contains minor amounts of metasediments and metavolcanics which subcrop just north of the site.

The clast proportions in the meltout unit also suggest that glacier advance was across lithologic contacts, assuming that there was some erosion of Archean bedrock in the area and subsequent subglacial meltout deposition of its materials. For example at site 2 Archean lithologies are roughly in equal proportion (although many metasedimentary clasts were decomposed (Fig. 2), could not be collected, and may be underrepresented in Fig. 5b) implying that ice advanced from the northwest, north, or northeast. As argued for lodgment till at nearby site 1, westward provenance would have resulted in more metasedimentary clasts and southward or eastward sources would have yielded more granitoid pebbles. Similar arguments can be made for sites 6, 9, and 10 where ice flow along lithologic units would have produced more metasedimentary and metavolcanic clasts. The upper meltout assemblages at sites 2 and 10 are from the weathering zone where many of the Paleozoic carbonate clasts had probably been dissolved and are thus underrepresented in Fig. 5b.

Finally, at site 3 the supraglacial till is dominated by subangular Archean clasts (67% in Fig. 5b; Fig. 3h) with granitic clasts clearly dominating, although many decomposed metasedimentary clasts could not be collected and the lithology may be underrepresented in Fig. 5b. Such an assemblage implies that erosion of the granitoid upland to the northeast of site 3, and upshearing of local basal debris, occurred when the glacier was active prior to final supraglacial meltout deposition. Glacial debris transport must have been from a northward source since metasediments are less abundant in the till.

Heavy minerals (0.125-0.250mm fraction) from till matrices were also examined in epoxy-mounted grain mounts (ground to optical thickness) under transmitted polarized light. The size chosen is the most representative of silicate particles formed by glacial comminution far from their source (DREIMANIS and VAGNERS, 1971; GWYN and DREIMANIS, 1979; HALDORSEN, 1981). Horneblende, pyroxene, garnet, epidote, opaques, tremolite-actinolite, and biotite are the most abundant heavies but each occurs in multiple bedrock types in the study area (STOTT, 1984), rendering provenance interpretations extremely difficult. Glacial reworking and mixing of mineral grains could also have obscured distinguishing signatures of source areas. About all that can be said is that a northward provenance for sites 1 to 4 is implied since significant areas of amphibole- and pyroxene-bearing rocks do not occur to the south of these sites toward Lake Superior. Light minerals comprise mainly quartz, plagioclase, and microcline. Microcline occurs mainly in the granitoid terrain underlying the northern part of the area (ibid.; Fig. 5b), and probably indicates a northerly source for most of the sites. Opaque minerals were studied in polished grain mounts under reflected light and include: hematite, pyrhotite, sphalerite, magnetite (some grains rimmed by hematite), and traces of pyrite. Gold inclusions were found encased in an epidotized augite grain, from calcareus subglacial meltout till at site 9, whose source is unknown. Many active and inactive minesites are scattered throughout the area which could be the sources for these metallic minerals, and hematite, magnetite, and pyrite are typical of the type of crystalline terrain that underlies the study area. Thus the opaques appear to be useless as glacial transport indicators in this case.

ICE STREAMING AND TILL DEPOSITIONAL HISTORY NORTH OF SUPERIOR

Both ice movement indicators and stone provenance support southwestward glacial advance of the Laurentide Ice Sheet in the Geraldton area, as determined by ZOLTAI (1967), SADO (1975), GARTNER (1979, 1980), and KRISTJANSSON et al. (in press). In the Hemlo area to the south, where carbonate tills are also abundant, ice advance was also southwestward (GEDDES and BAJC, 1985a, 1985b; GEDDES et al., 1985; GEDDES and KRISTJANSSON, 1986; HICOCK, 1986, 1987b). Calcareous lodgment tills in both areas are remarkably similar in texture and matrix and clast carbonate compositions, as are the calcareous meltout tills. This lithologic consistency suggests that the two areas are somehow related in the formation of their tills. In order to deposit areas of thick calcareous till on the Canadian Shield (GEDDES et al., 1985; GEDDES, 1986; GEDDES and KRISTJANSSON, 1986; KRISTJANSSON, 1986; KARROW and GEDDES, 1987; HICOCK, 1986, 1987a, 1987b, 1987c) comprising distal materials carried hundreds of kilometres downglacier from their sources, rapid glacial transport must be invoked. In Arctic Canada, along the northern margin of the Laurentide Ice Sheet, DYKE et al. (1982) and DYKE (1984) found wide bands of calcareous drift separated by zones of noncalcareous drift, as in the region north of Superior. They attributed this phenomenon to ice streams issuing eastward from the M'Clintock ice divide and separated by ice travelling at normal velocities. A similar scenario may also apply north of Superior. The concept of ice streaming and/or surging of parts of the Laurentide Ice Sheet is not new (eg. WRIGHT, 1969; PREST, 1969) but only recently has supporting geological evidence been found, especially belts of highly calcareous till on the Canadian Shield.

Considering another line of evidence, WRIGHT (1973) and BEGET (1986) have demonstrated that the Late Wisconsinan Superior and Michigan lobes of the southern margin of the Laurentide sheet had surface profiles much lower than those of modern ice sheets, based on profiles of lateral moraines and till rheology in Minnesota and Michigan, respectively. This indicates that ice lobes were thin and moving more rapidly than normal, as was also found by several authors, including: MATHEWS (1974), CLAYTON et al. (1985), and BEGET (1987), for the margin of the western part of the Laurentide sheet. In fact it is now thought that the Laurentide sheet profile was assymetric from north to south and east to west (FISHER et al., 1985; BEGET, 1986, 1987). Late Wisconsinan glacial flow north of Superior must have fed the Superior and Michigan lobes (MICKELSON et al., 1983; PREST, 1984) and so, by extrapolation, rapid flow may be implied for the study area. If the Late Wisconsinan spreading centres of the Laurentide sheet were long-lived (SHILTS, 1980, 1984; FISHER et al., 1985; BOULTON et al., 1985; VEILLETTE, 1986; DYKE and PREST, 1987), then rapid flow was probably sustained over thousands of years and is here called ice streaming rather than surging (CLAYTON et al., 1985).

Both modern and ancient ice streams were found to occupy broad bedrock troughs or areas of low relief (HUGHES, 1981; McINTYRE, 1985; BEGET, 1987) and some similarites may be drawn with the region north of Superior. The Albany valley is one of the most prominent in the James Bay Lowland and could have served as a major ice stream conduit (see PREST, 1969) leading to the Geraldton and Hemlo areas. The most thoroughly studied Ice Stream B of Antarctica spills over a bedrock step at the head of a large bedrock trough which enhances steam velocity (McINTYRE, 1985; VORNBERGER and WHILLANS, 1986). In the Hemlo area bedrock upland plateaus affected glacial dynamics and induced the deposition of calcareous lodgment till (HICOCK, 1986; 1987a, 1987b, 1987c). North of Geraldton a small upland area occurs upglacier from the belt of thick calcareous till (Fig. 1; KRISTJANSSON, 1986; HICOCK, 1987c). In both areas the uplands could have served as steps of ice flow enhancement such as found under Ice Stream B. Another similarity with Ice Stream B is the radial flow pattern near its margin. Striated and grooved bedrock, drumlins, and eskers also reveal radial flow patterns from southward to westward in both the greater Geraldton and Hemlo areas (GEDDES and BAJC, 1985a, 1985b; ZOLTAI, 1967; KRISTJANSSON et al., in press).

Thus a wet-based ice stream could have travelled up the Albany valley (lubricated by James Bay water?), and split to continue down the Drowning and Kenogami valleys, eroding soft Paleozoic sedimentary rocks and upshearing the entrained glacial debris to the englacial position, especially near the Paleozoic/Shield boundary (Fig. 6). Within the Laurentide marginal area zones of ice streaming may have been separated by zones of normal, slower marginal flow, and continued past Nakina and onto Geraldton to the west, and down to Hemlo in the eastern part of Fig. 6. The actual mechanism of ice streaming is addressed by HICOCK et al. (in press) who invoKe a combination of bed characteristics including deformable glacial substrata (BOULTON and JONES, 1979; BOULTON et al., 1985; BEGET, 1986) and subglacial drainage (CLAYTON et al., 1985; KAMB et al., 1985).

Upon encountering uplands in both areas ice probably initially flowed around them, eroding local bedrock and depositing KRISTJANSSON's (1984, 1986) local gritty, silty sand till near Geraldton and GEDDES' (GEDDES, 1984; GEDDES and BAJC, 1985a, 1985b; GEDDES et al., 1985; GEDDES and KRISTJANSSON, 1986) local subglacial till near Hemlo. Eventually ice thickness grew to the point where it flowed over the uplands (HICOCK, 1986; 1987a, 1987b, 1987c), inducing compressive flow and some stoss side upshearing as well as enhanced ice streaming and lee side extending flow with downward transport of englacial debris to the basal zone. The stoss side shear zone probably behaved like a standing wave in a water stream, with ice continuously passing through the zone with abundant distal debris and a small amount of locally eroded material. Most of the minor local material was probably upsheared into the ice and transported downglacier, beyond the study area. Penecontemporaneous lee side extending flow, into the structural trough south of Wildgoose Lake (Fig. 1), resulted in lodgment deposition of distally-derived englacial debris on the local tills. Once deposited, the silty lodgment till had low permeability and probably held water which enhanced ice streaming over it.

After the glacier reached its maximum extent it probably ceased internal flowage (even stagnation) north of Superior whereupon much of the englacial debris was laid down mainly by subglacial meltout. However, subglacial stream and debris flow activity was intimately associated with meltout as evidenced by the lenses of gravel and massive silty diamicton within the meltout unit. A model of subglacial meltout deposition north of Superior is schematically presented in Figure 7. It is based on SHAW's (1979, 1985) model but incorporates information gained from the Geraldton and Hemlo studies. Stage 1 (Fig. 7a) depicts a stationary slab of debris-rich basal ice resting on lodgment till with active ice lodging boulders onto the slab surface and represents a transition from lodgment to subglacial meltout in the area. Such a process of till formation has already been postulated by SHAW (1985, p. 38) and documented by DREIMANIS et al. (~~in press~~ 1987). In stage 2 (Fig. 7b) the slab has started to melt out and now contains a boulder pavement formed (in the meaning of SHAW, 1982, p. 1548) by lodgment but being deposited (ibid.) by meltout. More boulders are being lodged by active ice overriding the slab and large clasts are starting to settle into the melting ice and ice-rich sediment layers. Glaciofluvial activity and debris flows are occurring in englacial cavities where water is escaping from expanded ice sutures and conduits, as was postulated by HALDORSEN and SHAW (1982) and SHAW (1985). Ice layers and their melted out sedimentary deposits are settling over large clasts. After ice flow has ceased and meltout completed the resultant till sequence might resemble stage 3 (Fig. 7c).

Sediment layers drape over large clasts which commonly depress layers beneath them. Subglacial flow till and outwash lenses are intimately associated with subglacial meltout till and underconsolidated till diapirs have intruded sandy units in places. Finally, consistently striated boulder pavements (Fig. 2 site 7, and HICOCK, 1987b, Fig. 2 site 4) formed by lodgment have been deposited by subglacial meltout and preserved within parts of the subglacial meltout till unit.

For some reason a reactivation of the southern margin of the Laurentide sheet occurred which eroded the carbonate tills and left drumlins in the Geraldton area (ZOLTAI, 1967; KRISTJANSSON, 1984; KRISTJANSSON et al., in press) but deposited an upper calcareous lodgment till at Hemlo (HICOCK, 1986, 1987b). This event may correlate with the Nipigon phase of ZOLTAI (1965a) or the Cochrane readvance of BOISSONNEAU (1966) and SHILTS (1980). In both areas vigorous stoss side erosion of uplands occurred which upsheared more local materials to or near the ice surface. During final ice disintegration the upsheared, angular, supraglacial debris was lowered to the surface of the underlying subglacial meltout till by supraglacial meltout.

The entire till sequence can be explained with one glacial advance during the Late Wisconsinan Substage. This is supported by the lack of paleosols, weathering zones and rinds on clasts (although rotted granitoid and metasedimentary clasts are common at some sites), or organic layers within the drift sequence which might suggest interstadial intervals. Whether the tills were deposited entirely during general deglaciation of the area, or in part by ice advance during the Late Wisconsinan maximum, is very difficult to discern.

CONCLUSIONS:

In the Geraldton area four tills can be recognized, two of which were distally derived from at least 120km upglacier in the James Bay Lowlands. Ice movement indicators and pebble provenance demonstrate that ice advance was southwestward over a small upland area about 20km upglacier from Geraldton and Wildgoose Lake, across bedrock lithologic contacts. The deposition of all four tills can be explained by a single Late Wisconsinan glacial advance involving penecontemporaneous stoss side upshearing and lee side downward transport of calcareous englacial debris for lodgment deposition, as was modelled by HICOCK (1986, 1987b) for the Hemlo area. Eventually internal ice flow ceased and glacier downwasting formed subglacial, then supraglacial meltout tills, with an intervening glacial reactivation that carved drumlins into calcareous tills near Geraldton but deposited an upper calcareous lodgment till at Hemlo (ibid.).

The occurrence of thick belts of distal carbonate tills in both areas, with remarkable lithologic similarity between these areas, imply the presence of related zones of rapid ice movement within the southern margin of the Laurentide Ice Sheet. This is supported by reconstructions of low surface profiles for the Superior and Michigan lobes (WRIGHT, 1973; BEGET, 1986) which ice over this study area must have fed (MICKELSON et al., 1983; PREST, 1984). If Laurentide spreading centres were long-lived then this rapid flow was likely in the form of ice streaming rather than surging. Such an ice stream may have travelled out of James Bay up the broad Albany valley, between zones of normal ice velocities, and perhaps split down the Drowning and Kenogami troughs to the Geraldton and Hemlo areas, respectively. Zones of ice streaming would have traversed, eroded, and upsheared soft Paleozoic rocks of the James Bay Lowlands to the englacial position, especially near the Paleozoic/Shield boundary. Englacial ice streaming of this carbonate debris over bedrock steps in the Geraldton and Hemlo areas resulted in the deposition of calcareous silty lodgment till with low permeability. It probably held water and enhanced wet-based glacier flow over it, in effect providing a positive feedback mechanism for ice streaming.

On a practical note, drift prospecting would be hindered by the presence of the carbonate tills because they are mainly distally-derived and any ore dispersal trains in them would be too diffuse to trace back to their distant sources (GEDDES, 1984; KRISTJANSSON, 1986; HICOCK, 1986, 1987b, 1987c; GEDDES and KRISTJANSSON, 1986; KARROW and GEDDES, 1987). The supraglacial till comprises local materials, is richest in metals (including gold), and would be most likely to contain well-defined dispersal trains (HICOCK, 1986, 1987c). Kristjansson's local gritty, silty sand till and Geddes' local subglacial till would also be candidates for applying drift prospecting techniques. The carbonate tills, however, would serve as good buffers against acid precipitation, as well as cores in dams constructed to confine acidic mine tailings.

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Figure Captions

1) Topographic map of the Geraldton area with site localities. Larger lakes are shown (stippled) and branching solid lines represent roads. Contour interval is 60 m. Inset is a map of regional ice flow paths, Paleozoic (stippled), and Proterozoic (cross-hached) source rocks for Geraldton drift (modified after Shilts, 1980). LS=Lake Superior, G=Geraldton, H=Hemlo.

2) Diagrammatic lithostratigraphic sections with contoured equal area, lower hemisphere, stereographic projections of pebble long (a) axes. Mirror image, two-dimensional rose diagrams of striae on top surfaces of cobbles and boulders are presented beside the stereograms at the approximate level of their measurement in the section.

3) Geraldton till facies and representative structures. Striae symbols indicate approximate ice advance direction in the photo. Knife is 20cm long.: (a) Fractured, striated, and displaced bedrock slabs west of site 6 on Highway 11 with calcareous lodgment till infilling spaces between slabs (eg. at the knife point). Fractured bedrock is overlain by fissile lodgment till (left centre). Ice advance was toward the reader.; (b) Fissile lodgment till

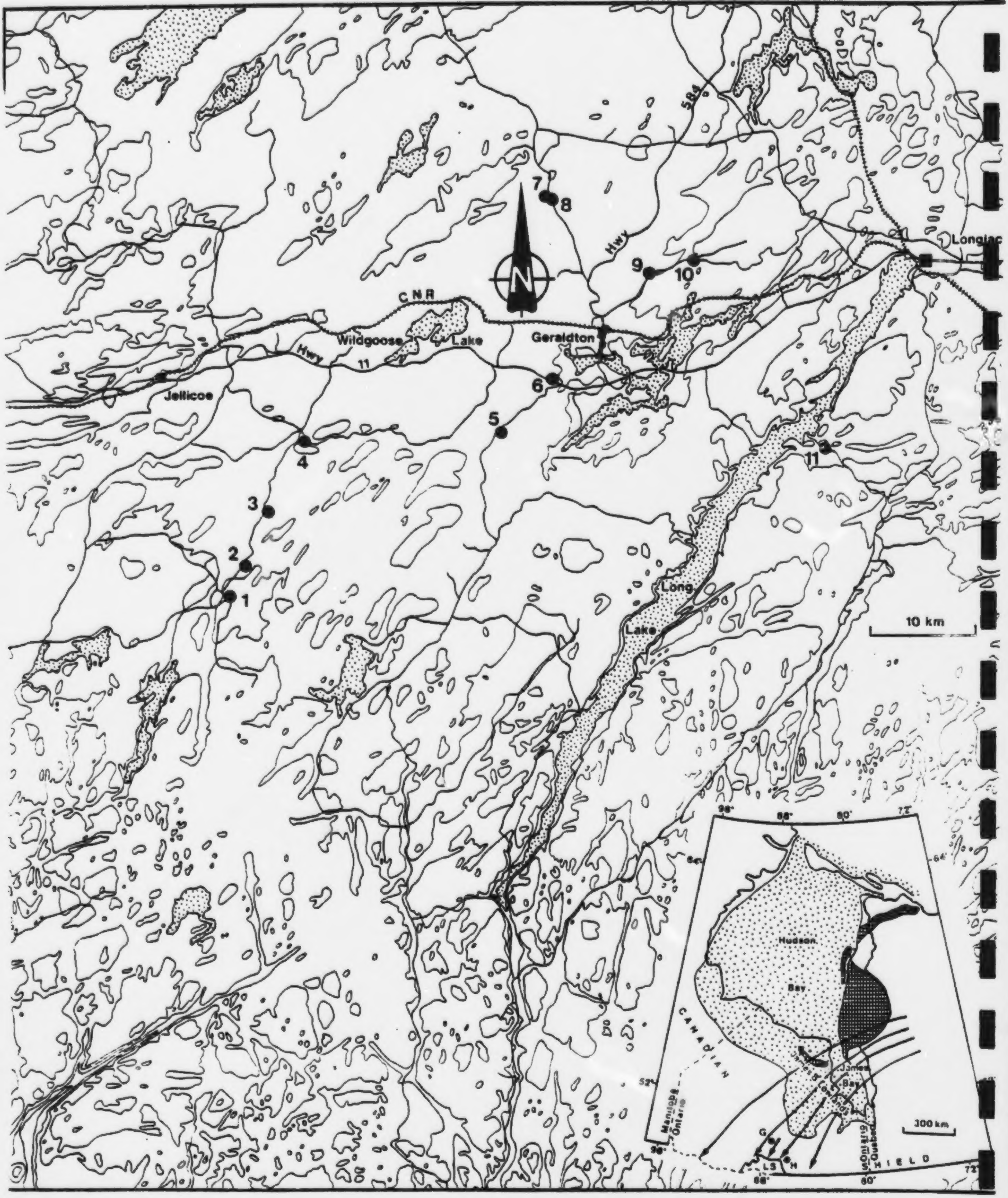
containing a sand-filled curved extension fracture above the knife handle at site 4. The fracture probably formed under glacial drag penecontemporaneously with till deposition.; (c) Fissile lodgment till containing a striated bullet-nosed boulder (part of a pavement) at site 4. Ice advance was toward the reader.; (d) Section through silt-enveloped flow lobes (darker shade) of remobilized lodgment till overlying undisturbed lodgment till (lighter shade) at site 6. Direction of flow is unknown. The knife lies between silt envelopes.; (e) Stone truncating bedding within subglacial meltout till at site 10.; (f) Delicate angular sand clasts (centre) within subglacial meltout till at site 9. A decomposed plutonic stone occurs to the left of the knife handle.; (g) Boulder pavements within subglacial meltout till at site 7. A buckled fine sand bed occurs above the knife, between two pavements. Ice advance was away from the reader during formation of the pavements.; and (h) Supraglacial meltout till with abundant subangular Archean clasts at site 3. The arrow points to the base of a calcareous till block with fewer, smaller, stones (upper right quadrant). The shovel handle is 12 cm wide (bottom right corner).

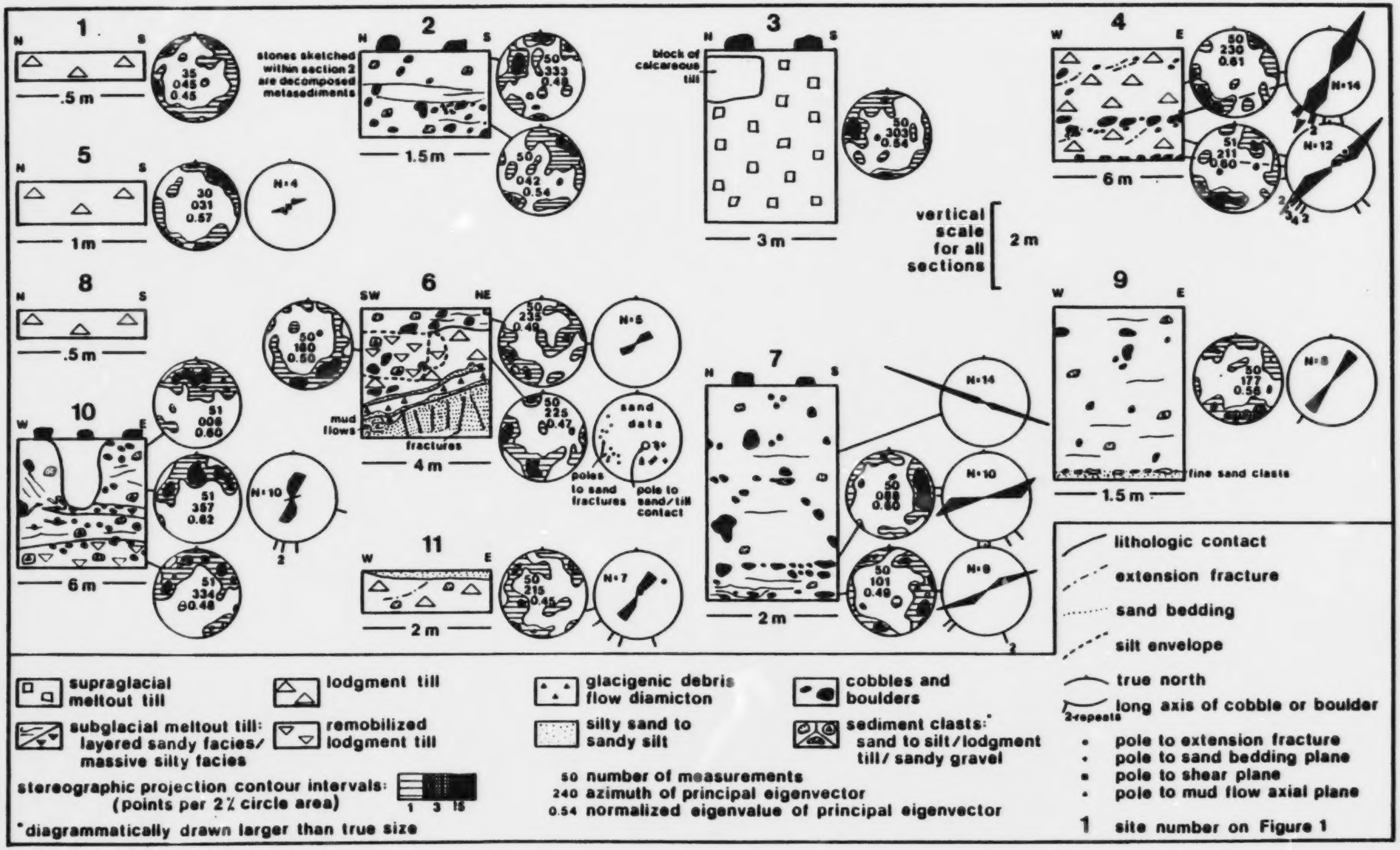
4) Laboratory data summary: (a) textural ternary; (b) matrix carbonate; and (c) clast carbonate.

5) Summary of glacial movement directional data: (a) kineto-stratigraphic diagram of ice advance directions, and (b) stone provenance diagram relating stratigraphically arranged pie charts to bedrock lithologies. Bedrock map is simplified from Stott (1984).

6) Hypothetical location of two zones of rapid ice flow (streaming; stippled) north of Lake Superior, within the marginal area of the Late Wisconsin Laurentide Ice Sheet. G=Geraldton, N=Nakina, H=Hemlo.

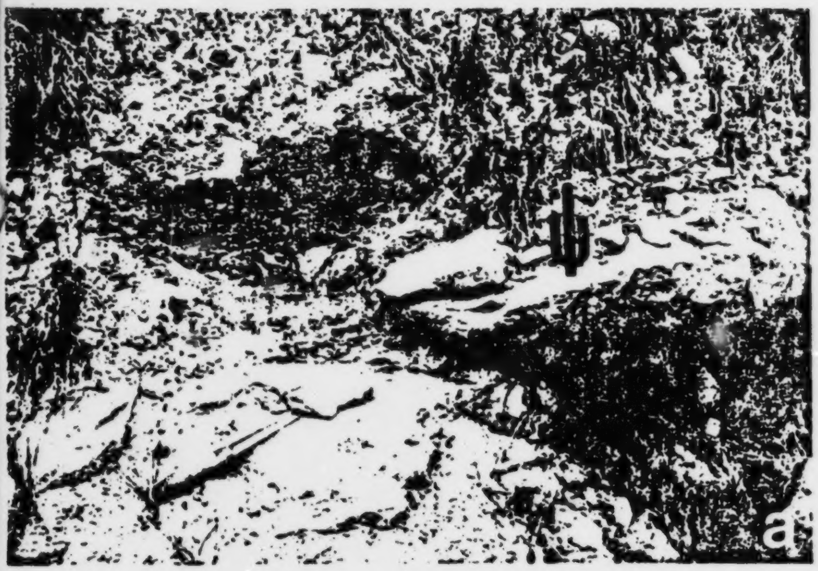
7) Schematic sequence of subglacial meltout deposition including boulder pavements formed by lodgment. (a) Lodgment on a stationary basal ice slab.; (b) Lodgment on stationary basal ice slabs melting out.; and (c) Resultant meltout till package with boulder pavements. The lodgment-meltout contact could be gradational. Not drawn to scale.

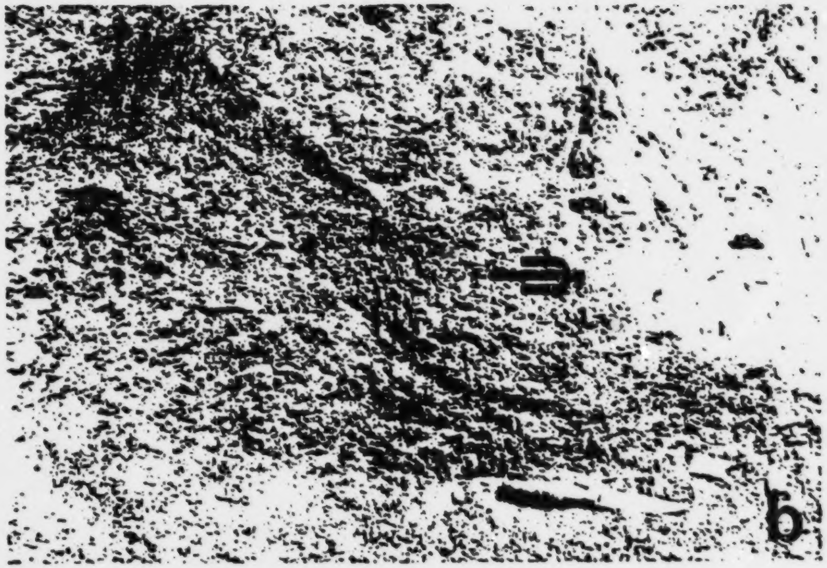

1
2
3
4
5
6
7
8
9
10
11
CNR
Hwy
11
584
Wildgoose
Lake
Geraldton
Jellicoe
Longlac
Long
Lake
10 km
N
96°
88°
80°
72°
64°
52°
Hudson
Bay
James Bay
James Bay Lowlands
CANADIAN
SHIELD
Manitoba
Ontario
Quebec
G
LS
H
300 km

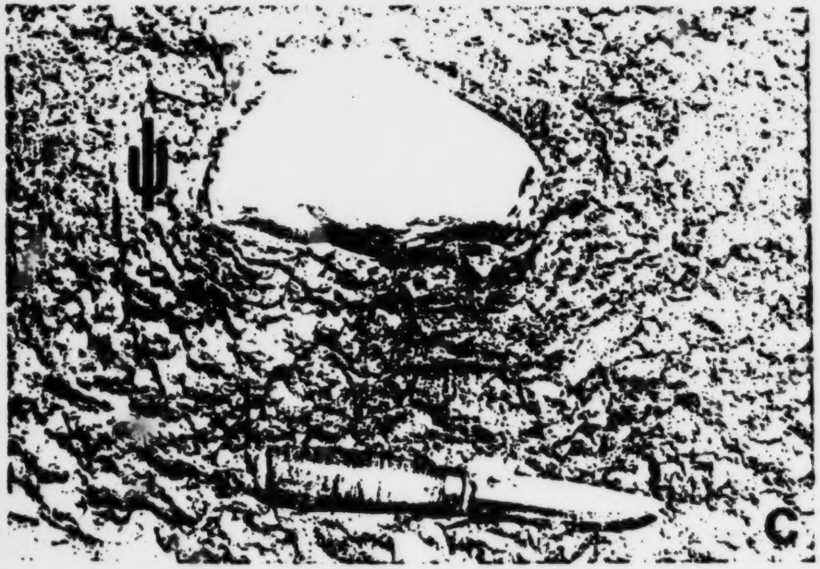

1
N
S
.5 m
35
045
0.45
2
stones sketched within section 2 are decomposed metasediments
1.5 m
50
333
0.48
50
042
0.54
3
block of calcareous till
3 m
50
303
0.54
4
W
E
6 m
50
230
0.61
51
211
0.60
N=14
N=12
5
1 m
30
031
0.57
N=4
vertical scale for all sections
2 m
8
.5 m
6
SW
NE
50
180
0.50
mud flows
fractures
4 m
50
235
0.49
50
225
0.47
N=6
sand data
poles to sand fractures
pole to sand/till contact
7
2 m
N=14
50
088
0.60
N=10
50
101
0.49
N=9
9
1.5 m
fine sand clasts
50
177
0.56
N=8
10
6 m
51
006
0.60
51
357
0.62
51
334
0.48
N=10
11
2 m
50
215
0.45
N=7
lithologic contact
extension fracture
sand bedding
silt envelope
true north
long axis of cobble or boulder
2-repeats
pole to extension fracture
pole to sand bedding plane
pole to shear plane
pole to mud flow axial plane
1 site number on Figure 1
supraglacial meltout till
lodgment till
glacigenic debris flow diamicton
cobbles and boulders
subglacial meltout till: layered sandy facies/ massive silty facies
remobilized lodgment till
silty sand to sandy silt
sediment clasts:* sand to silt/lodgment till/ sandy gravel
50 number of measurements
240 azimuth of principal eigenvector
0.54 normalized eigenvalue of principal eigenvector
stereographic projection contour intervals: (points per 2% circle area)
1 3 15
*diagrammatically drawn larger than true size

2

3







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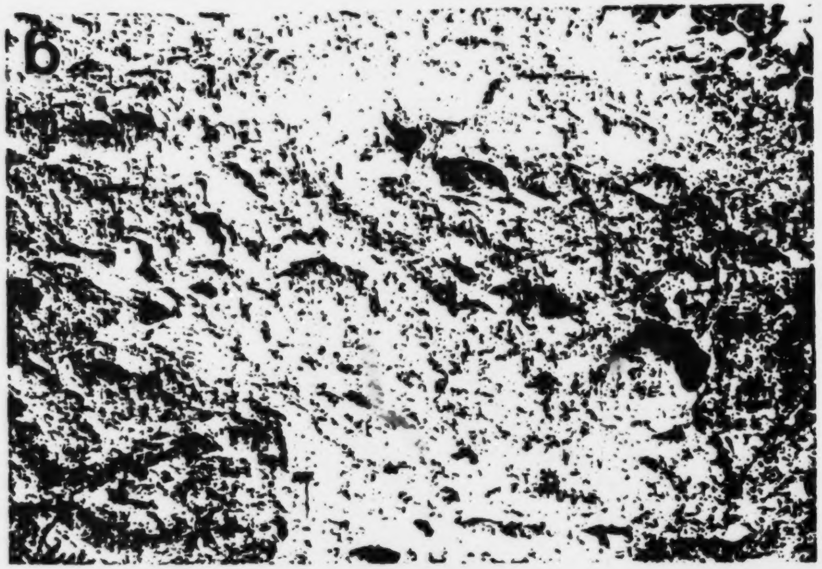
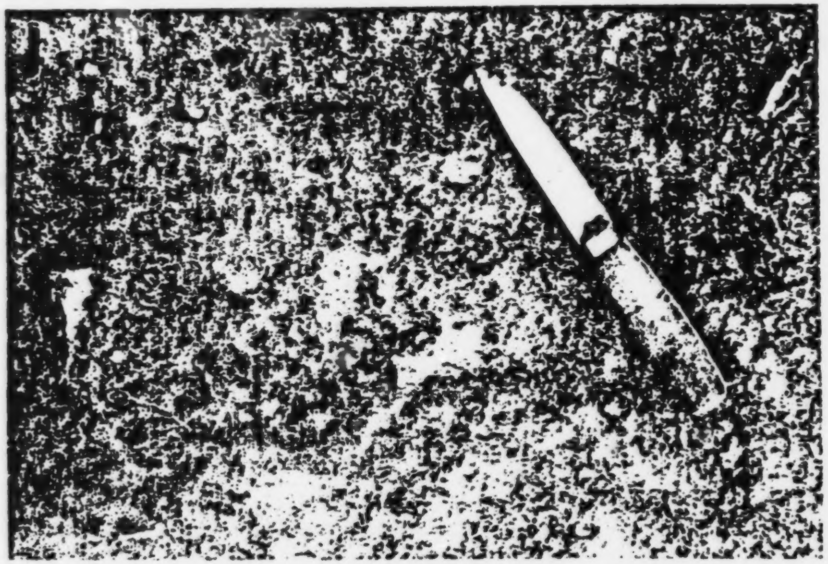
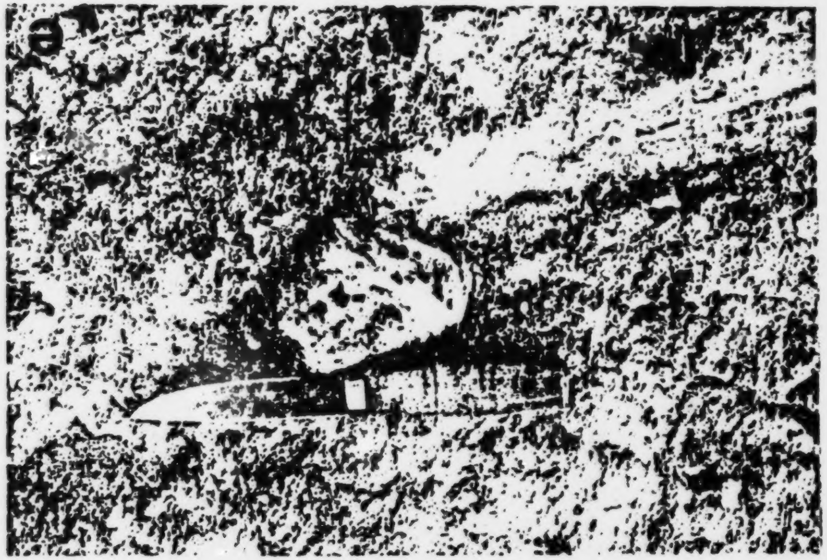
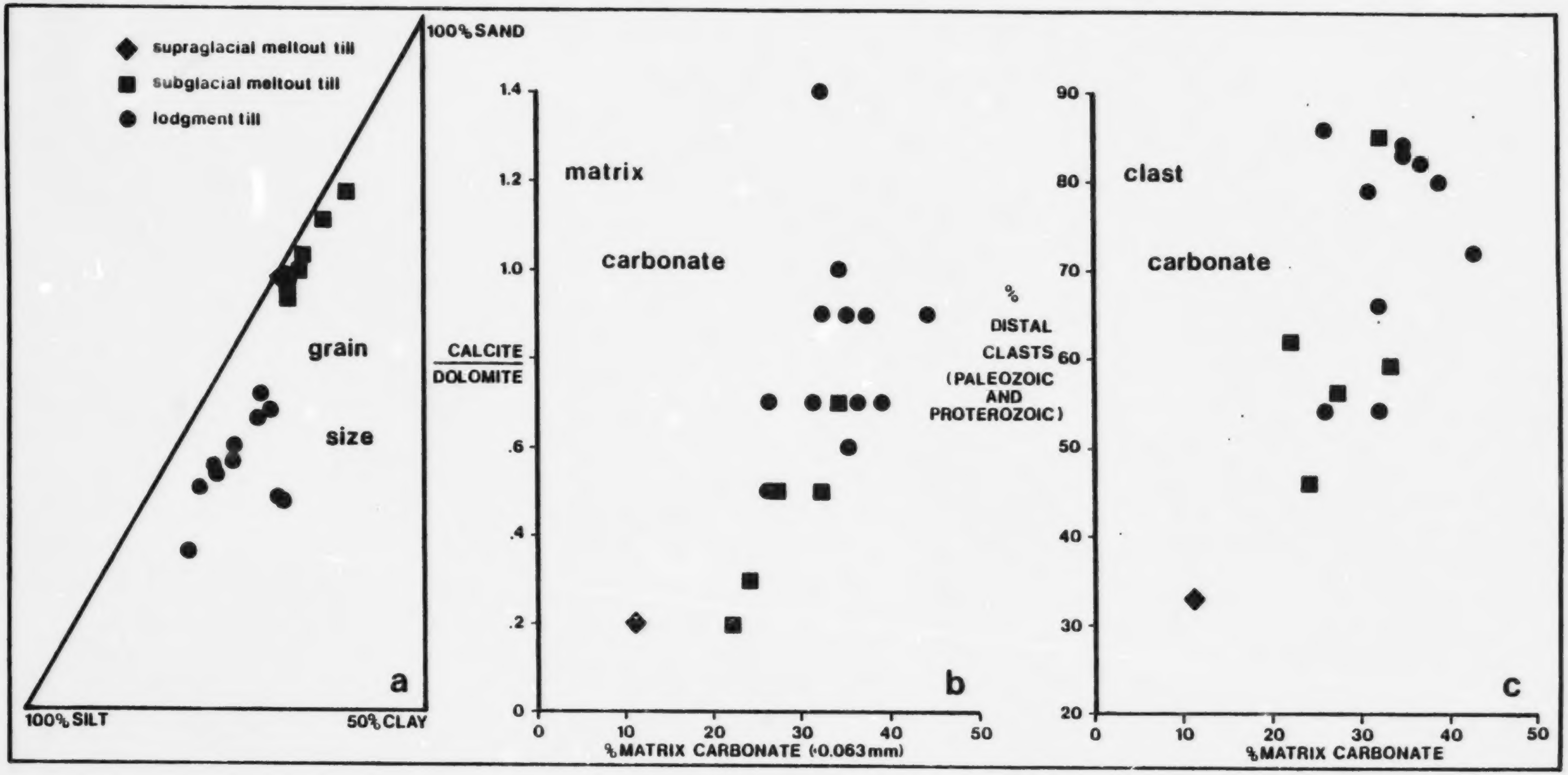


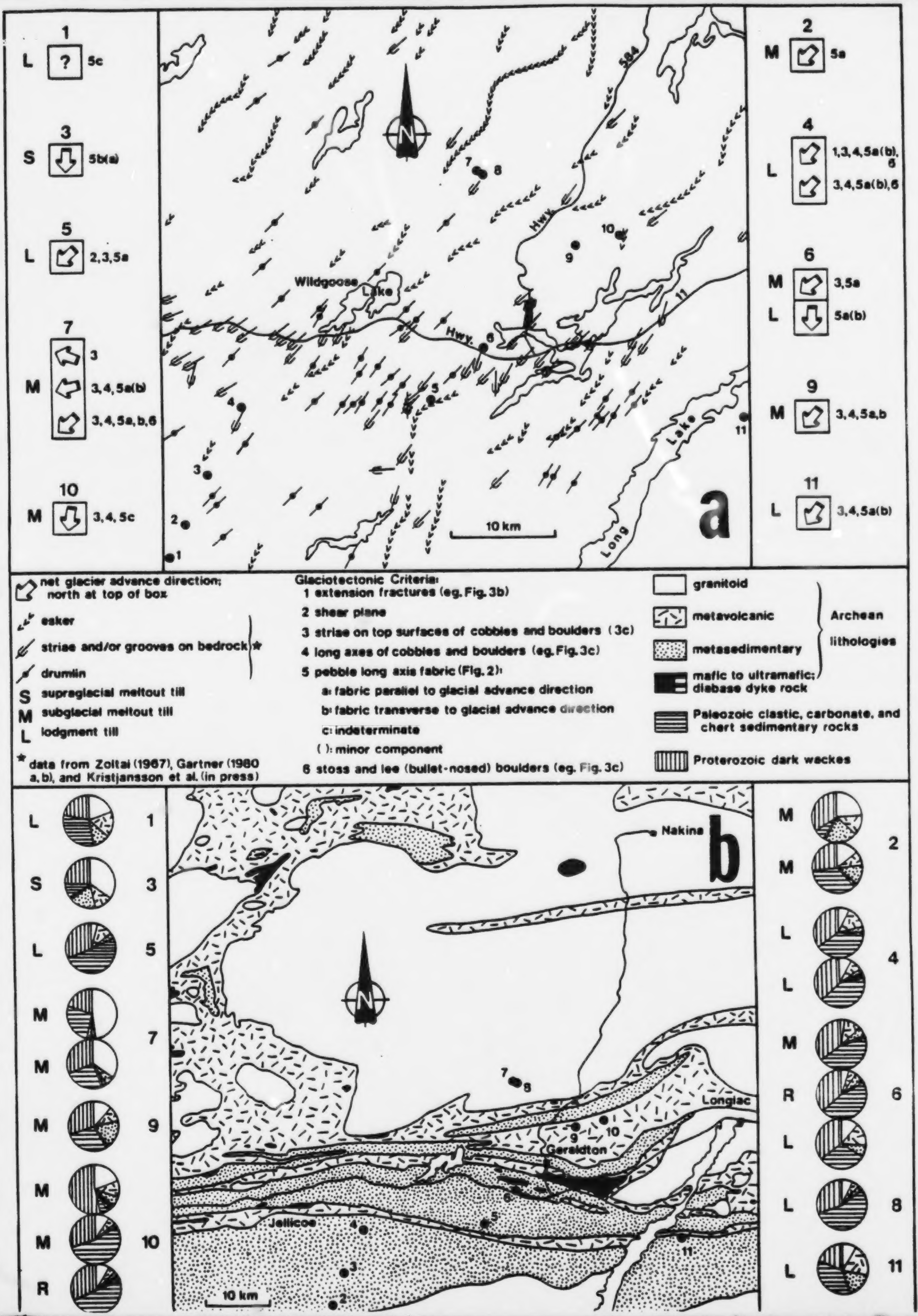




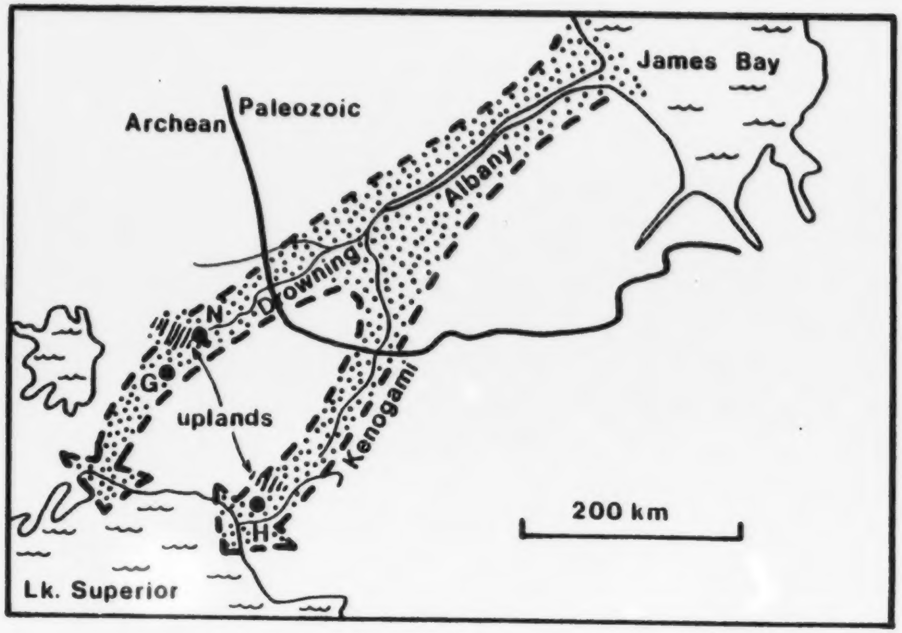

supraglacial meltout till
subglacial meltout till
lodgment till
100% SAND
100% SILT
50% CLAY
grain
size
a
CALCITE / DOLOMITE
1.4
1.2
1.0
.6
.4
.2
0
matrix
carbonate
b
0
10
20
30
40
50
% MATRIX CARBONATE (<0.063 mm)
% DISTAL CLASTS (PALEOZOIC AND PROTEROZOIC)
90
80
70
60
50
40
30
20
clast
carbonate
c
0
10
20
30
40
50
% MATRIX CARBONATE

4

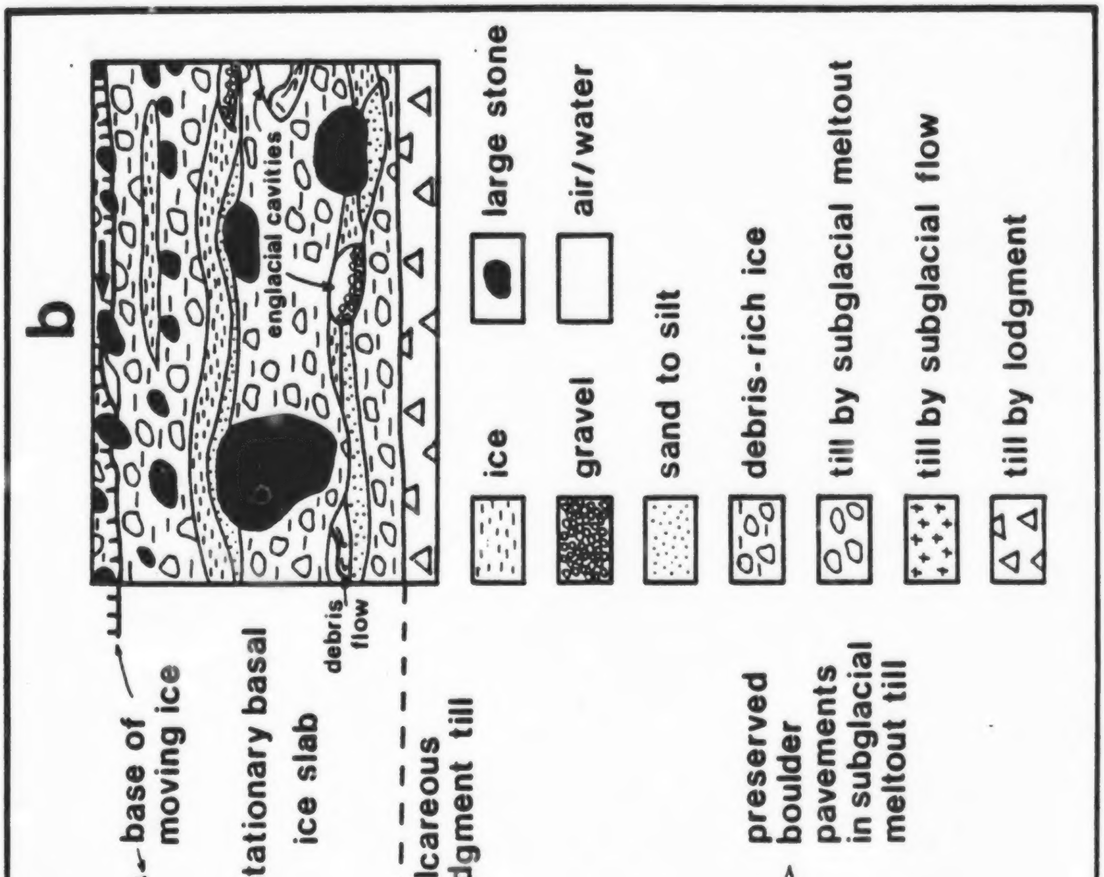
5



1 L ? 5c
3 S 5b(a)
5 L 2,3,5a
7 M 3; 3,4,5a(b); 3,4,5a,b,6
10 M 3,4,5c
2 M 5a
4 L 1,3,4,5a(b),6; 3,4,5a(b),6
6 M 3,5a; L 5a(b)
9 M 3,4,5a,b
11 L 3,4,5a(b)
Wildgoose Lake
Hwy. 11
Hwy. 584
Long Lake
10 km
a
net glacier advance direction; north at top of box
esker
striae and/or grooves on bedrock *
drumlin
S supraglacial meltout till
M subglacial meltout till
L lodgment till
* data from Zoltai (1967), Gartner (1980 a, b), and Kristjansson et al. (in press)
Glaciotectonic Criteria:
1 extension fractures (eg. Fig. 3b)
2 shear plane
3 striae on top surfaces of cobbles and boulders (3c)
4 long axes of cobbles and boulders (eg. Fig. 3c)
5 pebble long axis fabric (Fig. 2):
a: fabric parallel to glacial advance direction
b: fabric transverse to glacial advance direction
c: indeterminate
( ): minor component
6 stoss and lee (bullet-nosed) boulders (eg. Fig. 3c)
granitoid
metavolcanic
metasedimentary
Archean lithologies
mafic to ultramafic; diabase dyke rock
Paleozoic clastic, carbonate, and chert sedimentary rocks
Proterozoic dark wackes
L 1
S 3
L 5
M M 7
M 9
M M R 10
M M 2
L L 4
M R L 6
L 8
L 11
Nakina
b
Longlac
Geraldton
Jellicoe
10 km


James Bay
Archean
Paleozoic
Albany
Drowning
N
G
uplands
Kenogami
H
200 km
Lk. Superior

7


a
b
c
base of moving ice
stationary basal ice slab
calcareous lodgment till
debris flow
englacial cavities
diapirs
preserved boulder pavements in subglacial meltout till
ice
gravel
sand to silt
debris-rich ice
till by subglacial meltout
till by subglacial flow
till by lodgment
large stone
air/water

Appendix 5:

Abstracts presented at conferences by S.R. Hicock

HEMLO TILLS: UPLAND LEE SIDE DEPOSITION OF PALEOZOIC-RICH GLACIAL DEBRIS ON PRECAMBRIAN TERRAIN IN ONTARIO.

Hicock, Stephen R., Department of Geology, The University of Western Ontario. Presented at the Annual Meeting of the Geological Association of Canada at Ottawa in May, 1986.

Two (possibly three) tills in the Hemlo area contain abundant Paleozoic materials transported englacially from the James Bay Lowland, at least 200 km upglacier to the northeast, which renders them poor candidates for drift prospecting programs, but which makes them good buffers against acid precipitation (20-40% carbonates in <0.63 mm fraction). Depositional and glaciotectonic structures in the tills and substrata, as well as lithologic, textural, and geochemical analyses indicate that they are all ortho-tills deposited by the same glacier. The lower sandy silt carbonate till is fissile and compact and was deposited subglacially by lodgment and pressure melting. The middle silty sand carbonate till is less compacted and layered; deposited subglacially mainly by meltout, but in part by meltwater activity and mass movement. A possible upper sandy silt carbonate till is fissile, compacted, and was deposited by lodgment. A noncarbonate till capping the sequence is sandy, noncompacted, locally-derived, and was deposited by supraglacial meltout.

The depositional model envisages englacial ice thrusting over slower basal ice flowing compressively around upland plateaux. Upthrust englacial ice eroded the uplands, and upsheared entrained local debris to the top of the glacier. Once over the uplands extending flow, downshearing, and lodgment deposition of Paleozoic englacial debris occurred. After reaching its maximum extent the glacier stagnated and downwasted in the Hemlo area, depositing the meltout and supraglacial tills. The upper lodgment till may represent glacier reactivation during general stagnation.

CALCAREOUS TILL AND GOLD EXPLORATION NEAR GERALDTON, NORTHERN ONTARIO.

Hicock, S.R., Geology Department, The University of Western Ontario. Presented at the OGS open house at Toronto in December, 1986.

Eleven till exposures were studied to explain calcareous till on Precambrian terrain and determine its influence on gold exploration. The lowermost noncalcareous basal till comprises local materials and rests on bedrock but was not encountered in this study; calcareous lodgment till was the oldest found. It is compact, fissile, with 30-40% matrix carbonate ($c/d > 0.6$), 5-10% clay, abundant striated carbonate stones, and deformation structures. Overlying this is noncompacted subglacial meltout till which displays layering (including debris flows), with 25-35% matrix carbonate ($c/d < 0.6$), < 5% clay, striated carbonate stones, and clasts of compact till, sand, and gravel. Commonly capping the sequence and mantling kames is sandy supraglacial meltout till with large granitic blocks and negligible carbonate matrix or stones.

Early ice advance in the area was to the southsouthwest, and later southwest, based on bedrock and till boulder striae, stone fabrics, drumlins, eskers, roches moutonnees, and deformation structures in till. The till sequence can be explained by one glacial event. This involved local ice streaming and rapid transport of large amounts of calcareous Paleozoic materials derived from the James Bay Lowlands, in the marginal area of the Laurentide ice sheet. The ice stream spilled over a bedrock step north of Geraldton, and into a structural trough southwest of Wildgoose Lake where the calcareous debris was deposited as lodgment till. Following the Late Wisconsinan glacial maximum internal glacier flow ceased and subglacial meltout till accumulated in the trough. However, a later flow reactivation caused upshearing of the granitic bedrock step, carrying local debris to the glacier surface and streamlining calcareous drift into drumlins. Final downwasting resulted in supraglacial deposition and ice disintegration landforms.

The calcareous tills are thus a hindrance to gold exploration in the Geraldton area. They have been transported for at least 120 km from their Paleozoic source and any ore dispersal fans in them would be too weak and diffuse to trace reliably back to source. The local basal till is the one to use for drift prospecting. However, the calcareous drift serves as a good buffer to acid precipitation. The calcareous lodgment till would make good buffering fill for cores in dams holding acidic mine tailings.

ICE STREAMING AND CARBONATE TILL GENESIS ALONG THE SOUTHERN MARGIN OF THE LAURENTIDE ICE SHEET.

Hicock, Stephen R., Dept. of Geology, University of Western Ontario. Presented at the 12th INQUA Congress at Ottawa in August, 1987.

The Hemlo and Geraldton areas north of Lk. Superior contain tills (including lodgment) rich in matrix and clast carbonates derived >120km from their Paleozoic sources in the James Bay Lowlands. The occurrence of these two belts of thick, commonly silty calcareous tills adjacent to belts of thin, sandy local drift infers rapid glacial transport of distal carbonate debris between areas of slower ice.

The broad Albany valley probably served as the conduit for an ice stream during Laurentide ice sheet expansion. The stream probably deepened the valley, incorporating carbonate materials and upshearing them to the englacial zone at the Paleozoic's contact with resistant Precambrian bedrock. It may have split to flow down the Drowning and Nagagami valleys. Upon streaming over bedrock steps upglacier of the study areas, extending flow and downward transport of distal debris to the basal zone resulted in deposition of calcareous silty lodgment till. This probably had low permeablity, allowing subglacial meltwater pressures to build, enhancing the rapid flow of the ice stream, which probably became part of the Superior lobe.

After the glacial maximum, downwasting produced subglacial meltout till. Glacial reactivation upsheared local upland materials to the glacier surface, formed drumlins near Geraldton, and more lodgment till near Hemlo. Final disintegration produced locally-derived supraglacial meltout till. Another ice stream may have occupied the Moose valley, forming calcareous tills near Timmins.

meltout deposition of its materials. For example at site 2 Archean lithologies are roughly in equal proportion (although many metasedimentary clasts were decomposed (Fig. 2), could not be collected, and may be underrepresented in Fig. 5b) implying that ice advanced from the northwest, north, or northeast. As argued for lodgment till at nearby site 1, westward provenance would have resulted in more metasedimentary clasts and southward or eastward sources would have yielded more granitoid pebbles. Similar arguments can be made for sites 6, 9, and 10 where ice flow along lithologic units would have produced more metasedimentary and metavolcanic clasts. The upper meltout assemblages at sites 2 and 10 are from the weathering zone where many of the Paleozoic carbonate clasts had probably been dissolved and are thus underrepresented in Fig. 5b.

Finally, at site 3 the supraglacial till is dominated by subangular Archean clasts (67% in Fig. 5b; Fig. 3h) with granitic clasts clearly dominating, although many decomposed metasedimentary clasts could not be collected and the lithology may be underrepresented in Fig. 5b. Such an assemblage implies that erosion of the granitoid upland to the northeast of site 3, and upshearing of local basal debris, occurred when the glacier was active prior to

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